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LIFORNIA DIVISION OF MINES AND GEOLOGY

PECIAL REPORT 149

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SPECIAL REPORT 149

PALEOSOLS OVERLYING THE FOOTHILLS FAULT SYSTEM NEAR AUBURN, CALIFORNIA *

By

Glenn Borchardt, Salem Rice, and
Gary Taylor

1980

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ABSTRACT

Soil strata overlying the Foothills fault system near the proposed Auburn dam include a thin, relatively unweathered colluvial unit and remnants of a paleosol developed in Mesozoic bedrock. The paleosol was previously thought to have formed prior to 100,000 B.P. (years before present), but during this study we found support for an alternative hypothesis: *the "Foothills paleosol" was an active soil between 9,000 and 130,000 B.P.* Significantly, the overlying "Foothills colluvium" has been carbon–dated at 9,130 ± 170 B.P. (at one locality), an age coinciding with the widely known early Holocene pluvial period. Soil development in the colluvium is within that expected for the present climate and for Holocene materials of moderate clay content. In contrast, development within the paleosol is characterized by *in situ* clay formation from bedrock with very little colluvial interference and under conditions of greater effective precipitation than at present. Traces of cool–weather pollen (spruce and hemlock) preserved within certain ideally–situated paleosols indicate that they were formed during a glacial period rather than during an interglacial period, as previously supposed.

With the above considerations in mind, soils and clays related to possible dating of fault features within the Foothills paleosol were evaluated with techniques involving particle size distribution, pH, Ca/Fe ratios, and clay mineralogy. Of the six exploration sites overlying the Foothills fault system, two (Spenceville and Hubbard Road) showed evidence for possible Holocene fault movement. Two other sites (Smith Property and Railroad Tunnel) had features that could be interpreted as involving post–Illinoian (130,000 B.P.) fault movement. On the other hand, the paleosol overlying part of the Maidu East fault zone in trench ST–65 near the proposed Auburn dam shows no evidence of movement since the beginning of the Wisconsin (75,000 B.P.) and perhaps since the end of the Illinoian (130,000 B.P.). At The Knolls site south of the proposed dam, evidence for movement was equivocal, but the Luneman Road site offered evidence for Holocene soil movement involving slumping or creep associated with slickensides that were possibly tectonically generated. In short, we conclude that the Foothills fault system exhibits evidence of probable minor Holocene movement as well as evidence of more extensive movement during the period 9,000–130,000 B.P., and should therefore be considered tectonically active.

PALEOSOLS
OVERLYING THE FOOTHILLS FAULT SYSTEM NEAR AUBURN, CALIFORNIA

By
Glenn Borchardt[1], Salem Rice[2], and
Gary Taylor[3]

INTRODUCTION

he occurrence of the Oroville earthquake on August 1, 1975
dgers, 1975; Sherburne and Hauge, 1975) revealed that the
thills fault system of the Sierra Nevada was more active than
iously supposed. The U.S. Bureau of Reclamation, which at
time had already initiated foundation excavation and treat-
t for the construction of the "world's largest thin arch dou-
urvature high dam" (Carter, 1977; Williams, 1978) at a site
e Foothills fault zone (Gardner and others, 1957) near
urn, only 80 km south of Oroville, began seeking assurance
faults beneath the foundation were "inactive." (The U.S.
au of Reclamation considers a fault "inactive" if no move-
has occurred along its length during the last 100,000
s.)

bsequent investigations (Bennett, Taylor, Toppozada,
; Bennett, 1978) found that the dam site is located in an area
e stresses of the earth's crust are likely to be taken up along
s and talc zones that were formed 70 to 230 million years
during Mesozoic time. Since neither Tertiary rocks nor
ger units are present in the dam foundation, it was impossi-
determine whether or not movement occurred there dur-
Holocene time. However, the extensions of these faults
th younger strata and the relationships of these faults to
tures outside the foundation area were studied. It was found
movement along some of the Mesozoic structures has oc-
d since the Tertiary Mehrten Formation was deposited
nine million years ago (Frei and others, 1977; O'Brient,
p. 11). For example, along the Maidu East fault zone,
n 800 meters of the right abutment of the proposed dam,
meters of lateral and five meters of vertical offset occurs;
within 284 meters of the abutment, about 60 centimeters of
ent vertical offset occurs in Tertiary rocks. Such findings
determining the dates of the most recent movements with-
Foothills fault system even more crucial to the U.S. Bu-
of Reclamation.

e approach to determining these dates involves the use of
sols (fossil soils) (Shlemon, 1977a, 1977b; U.S. Geological
y, 1977; Borchardt, Taylor, and Rice, 1980). Woodward–
Consultants (Schwartz and others, 1977; Swan and Han-
977) used paleosols to date movements along the Foothills
ystem. In their studies these paleosols (hereinafter referred
he "Foothills paleosol," Table 2) are considered to be over
00 years in age; if a fault is overlain by an undisturbed
ol, they conclude that the fault has been inactive for at
100,000 years.

Initially our aim in this study was to answer the following questions: (1) Is the "Foothills paleosol" really 100,000 years old? (2) Has it been disturbed by fault movement since that time? It soon became evident, however, that neither of these questions can be answered directly and unequivocally. This being the case, we took as our objective the more modest task of answering the following questions: (1) What are the physical relationships among these paleosols, the overlying colluvial cover, and the underlying parent material? (2) What are the physical, chemical and mineralogical characteristics of the paleosols, and are they consistent with a 100,000–year age? (3) What features within these paleosols can be considered (or mistakenly considered) evidence for fault movement? The answers to these three questions led to a hypothesis concerning the age of the "Foothills paleosols" and its probable disturbance by tectonic activity.

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We would especially like to thank those personnel of the U.S. Bureau of Reclamation, Woodward–Clyde Consultants, the California Department of Water Resources, and the U.S. Geological Survey for their help in providing trenches and access to sites as well as for their many helpful discussions concerning the soils and the geology.

SOIL STRATIGRAPHY AND CHRONOLOGY

Paleosols are useful for dating because they represent soil formation during a period of relative landscape stability and they are usually buried under materials deposited during a period of landscape instability. If the latest sediments show evidence of soil formation, an additional period of landscape stability can be inferred.

This type of sequence characterizes many of the soils overlying the Foothills fault system. Generally, a well–developed, clayey paleosol is overlain by a generally oxidized, coarse–textured colluvial unit that in most places is about 30 to 60 cm thick. The paleosol is commonly reduced and is usually developed residually on bedrock. Soils in the colluvial unit exhibit very weak to

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moderate development even though their clay contents at the time of deposition were considerable. This wide contrast in degree of development shows that the paleosol was subject to soil weathering for long periods of time while the colluvial unit was not.

Prior to recent studies of the Foothills fault system sponsored by the Bureau of Reclamation, very little work had been done on the relative age of colluviation and of the paleosol in the foothills. Swan and Hanson (1977; 1978), Schwartz and others (1977), as well as Shlemon (1977a; 1977b; 1978), started their work with the basic assumption that colluvial events in the foothills must have coincided with the slow advance of glaciers in the Sierras. For example, Swan and Hanson (1977, p. 21) state that:

> The episodes of colluviation and alluviation in the foothills correlate with the eposides of glaciation in the mountains; the episodes of landscape stability and soil formation correlate with the interglacial stages.

Our studies cast considerable doubt on this assumption. It appears that the glacial period may, in fact, have been one of relative slope stability and significant soil formation in the foothills. We find a good deal of support for the hypothesis that colluviation in the foothills is almost exclusively a result of the early Holocene pluvial period about 9,000 B.P. (years before present) that followed the rapid recession of the Tioga glaciers at the end of the Pleistocene. The paleosol, of course, is pre–Holocene with a period of formation that may extend back to another really rapid wet–to–dry climatic change perhaps 130,000 years ago. An implication of this hypothesis is that tectonic movements recorded within the paleosol are likely to represent only the latter part of that 9,000– to 130,000–year development.

Age of the Foothills Colluvium

As used in this study, the term "Foothills colluvium" is a generalization for the surficial soil and transported rock unit that mantles the "Foothills paleosol" or the undisturbed bedrock within the western Sierra Nevada. Descriptions of colluvium within the foothills appear in Swan and Hanson (1977; 1978), Schwartz and others (1977), Shlemon (1977a; 1978b, 1978), and Borchardt, Taylor, and Rice (1980). In general, the colluvium takes on the highly variable character of the local bedrock and the residual soil from which it was derived. Often, the unit has a distinctive stoneline at its base (Borchardt, Taylor, and Rice, 1980, Figures 4, 5, and 7). In places, the Foothills colluvium is over a meter thick, especially where it grades into local alluvium such as at the Smith Property and Bayley House sites (Figure 1). At other places, such as on ridge tops and bedrock outcrops, it is absent.

An important characteristic of the Foothills colluvium is soil development within the unit. This is judged to be approximately one tenth that within the Foothills paleosol. Additionally, each of what might be described as separate units within the Foothills colluvium has weak to moderate soil development. Later we will show that any reactivation of colluvial movement and subsequent soil development within these more recent units of the Foothills colluvium took place during Holocene time.

Radiocarbon dates

Radiocarbon dates for a generally oxidized surficial unit that is less than a meter thick must be evaluated with caution. Suitable carbon–containing materials have yet to be found within Foothills colluvium. The only reliable date with implications the age of the colluvium in the foothills appears to be that Swan and Hanson (1977, p. 74). They obtained a date 9,130 ± 170 B.P. on charcoal collected at a depth of 2.4 m at bottom of an alluvial fill at the Bayley House site in a relativ flat–lying valley on a ridge top above Auburn dam site (Fig 1). This Holocene alluvium "grades laterally into the upperm colluvium that mantles the hillslopes" (p. 74). Schwartz others (1977, p. A–9) remark that the "colluvium and alluv in this valley are...equivalent to the late Modesto–Holocene luvium and alluvium" they found elsewhere. (The late Mode Formation of the Great Valley is between 29,000 and 11, B.P.) The 9,000 year–old colluvium directly overlies isola remnants of the Foothills paleosol at this locality. If an ol pre–Holocene alluvium or colluvium ever existed in this val it must have been eroded away in spite of the generally gradients in the area. There are no remnants of alluvium colluvium that could be dated earlier than Holocene. Thus, available evidence at the Bayley House site suggests that pale development was interrupted by extensive slope stripping ab 9,000 years ago. There is no evidence for an early Wisco colluvial event.

The early Holocene pluvial period

There is a great deal of evidence suggesting that the colluv dated 9,130 B.P. at the Bayley House site is representative period of colluviation that took place throughout the West result of a single pluvial event.

To the east, for example, in Nevada and Utah, Pleisto Lakes Lahonton and Bonneville were undergoing a resurg at about the same time (Broecker and Van Donk, 1970; Broe and Kaufman, 1965; Croft, 1968). The sharp fluctuations in level of Lake Lahontan (Figure 2) are particularly signifi for evaluating the age of colluviation in the western Sierra vada foothills. The level of this lake dropped almost 400 feet then rose the same distance again within a 3,000 year pe centered at about 11,000 B.P. These sharp fluctuations appe have been a result of the "abrupt (less than 3,000 years f full–cold to full–warm)" climate change at the end of the P tocene (Figure 3) identified by Broecker and others (196 300). The high water level during the late Pleistocene sugg that this period enjoyed a cool and humid climate likel promote more vegetation in the Sierra foothills than prese flourishes there. Thus, the hill slopes in the region would been more stable—not less stable, as Swan and Hanson ass (1977, 1978)—than they are at present. The 400 foot dro water level, with the lowest level occurring at about 11,000 suggests that the Pleistocene was brought to a close by a rela ly short period of extreme aridity and warmth, during w time vegetation in the foothills would thin considerably, lea slopes vulnerable to erosion. The resurgence of the lake bet around 11,000 and 9,500 B.P. suggests that an extremely climate prevailed during that period. As Gile has shown (1 p. 344–345), a temporary return to pluviality after the blishment of arid conditions results in extensive erosion. T we would expect the foothills, whose slopes had lost muc their vegetative cover during the arid period, to experience h erosion during this period. And, indeed, a recent study by H en and Marchand (1980, p. 9) presents strong evidence fo occurrence of erosion and colluviation in the Sierra foot since the end of Pleistocene glaciation. They found that exte alluvial deposits from the Calaveras River, which drains a area of unglaciated Sierra Nevada foothills, overlie out

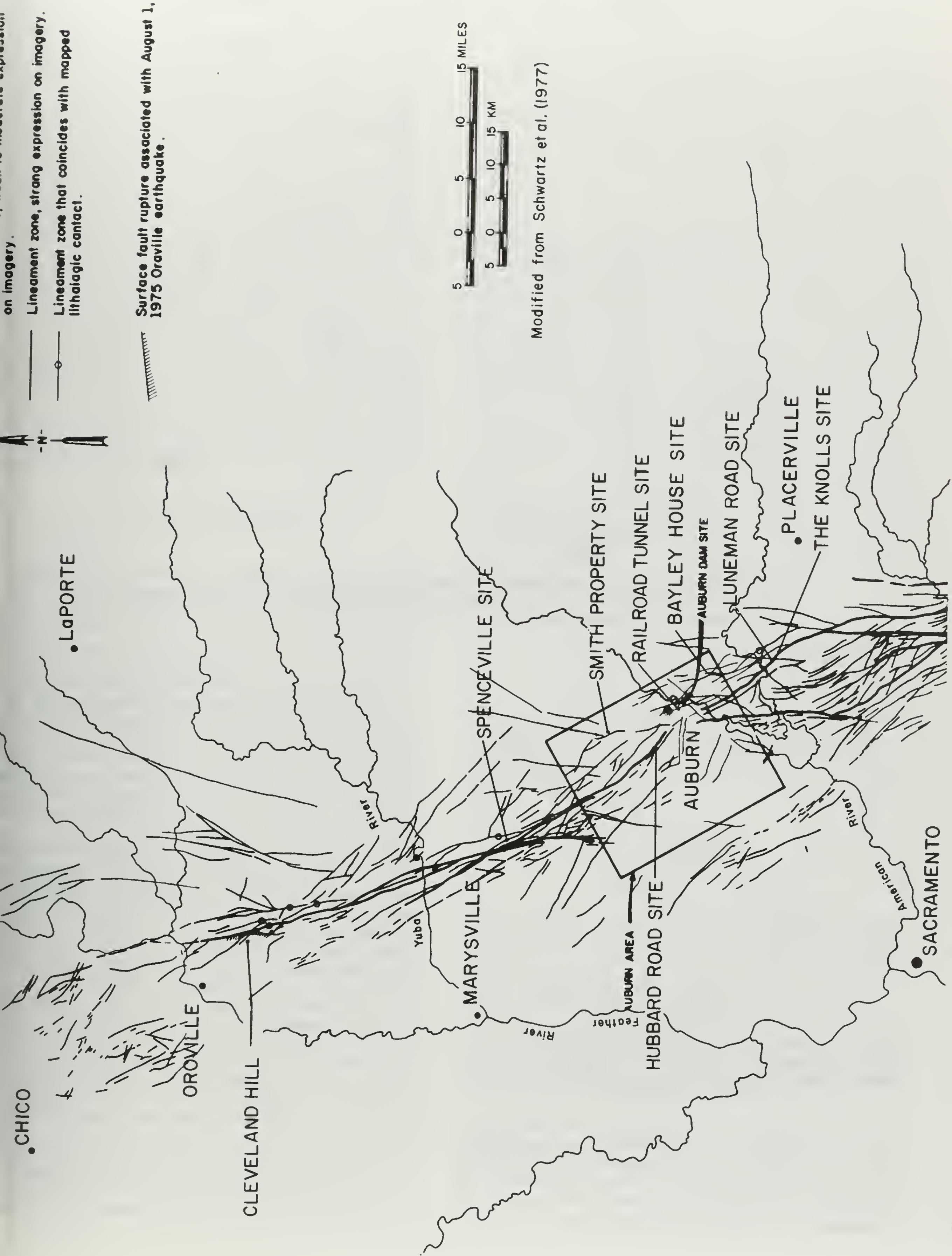


Figure 1. Locations of paleosol sites along the Foothills fault system north and south of the proposed Auburn dam.

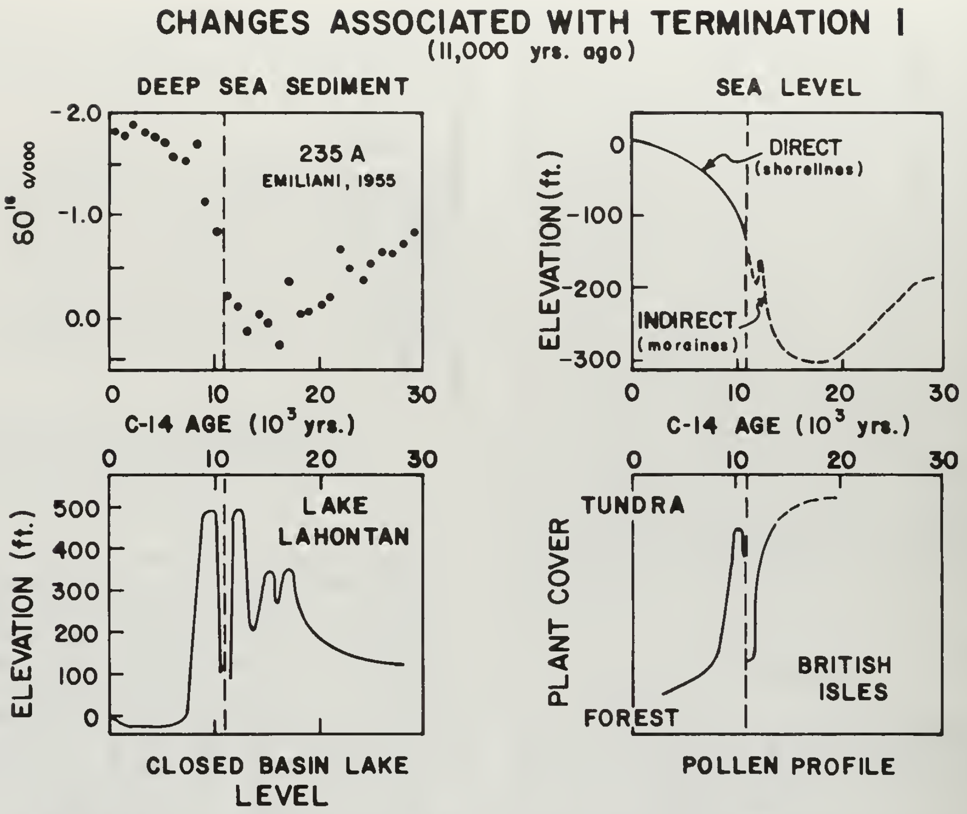


Figure 2. Changes associated with termination I. Although the O^{18} curves show a unilateral change from cold to warm, glacial deposits, pluvial lake shorelines, and vegetation remains clearly show at least one sharp oscillation between 9,000 and 13,000 years ago (Broecker and Van Donk, 1970, Figure 8).

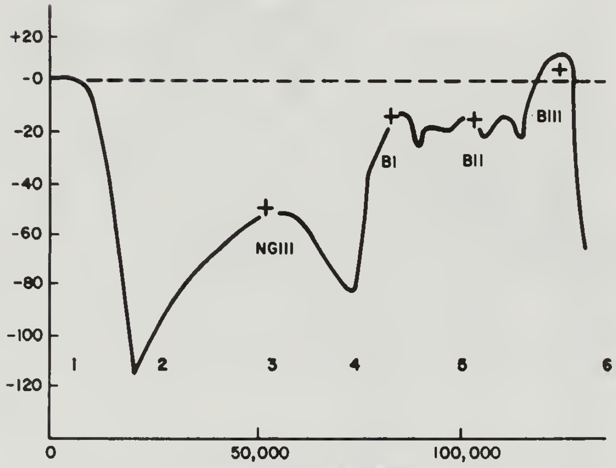


Figure 3. Glacio-eustatic sea level curve for the past 130,000 years derived from oxygen isotopic measurements in V28–238, compared with estimated sea levels derived from work on Barbados (B1, B11, B111) and New Guinea (NG 111) (Shackleton and Opdyke, 1973, Figure 7).

from the Mokelumne River, which primarily drains higher glaciated areas. The Mokelumne River outwash was deposited during the warm, arid period of glacial thaw that ended the Pleistocene. The deposits from the Calaveras River overlying the Mokelumne River outwash must therefore be the result of erosion and colluviation that took place since then.

To the south, Tulare, Buena Vista, and Kern Lakes in the
Joaquin Valley were refilling at about this time after the
period which followed the rapid warming trend that ended
Pleistocene (Croft, 1968). Croft (1968, p. B155) obtain
radiocarbon date of 9,040 ± 300 B.P. from wood in sand
that interfinger with the upper lacustrine clay underlying
Buena Vista and Kern lakebeds; he suggests that "the age ge
ally agrees with the concept of a pluvial period about 8,00
10,000 years ago."

Van Devender's work (1977) with radiocarbon-dated pac
middens also corroborates the occurrence of this pluvial pe
He found that southwestern deserts had woodland plant
munities as recently as 8,000 years ago. In addition, his
suggests that a pluvial climate tends to persist for a conside
period of time after the end of a glacial climate and that
desert and grassland communities returned to the South
only after heavy winter precipitation diminished.

Flooding, erosion, and rapid alluvial deposition also occu
at about the same time in Humboldt County, California (J
son, 1977, p. 164). Three Douglas fir logs buried at 8, 16,
31 meter depths in a section (35 meters thick) of alluviu
Bull Creek gave essentially identical radiocarbon ages—
9,500 B.P. The spacing of the logs in the section indicates
at least two-thirds of the deposit may be a result of a s
pluvial event.

During the pluvial period that occurred between about 1
and 8,000 B.P. the residual soils that developed during the g
epoch (the Foothills paleosols) were subjected to erosive f
of an intensity greater than could probably occur at pr

ackenridge (1978, p. 30), working in the American South-st, observes that "Stability was followed by early Holocene l–slope stripping, first of fines and then of remnant hill–slope ulders." Indeed, early Holocene slope stripping has been not-d in the Middle East as well as in the southwestern United ites (Bull and Schick, 1978).

In view of this evidence, we conclude that, in all probability, ost of the colluvium that overlies the Foothills paleosol was posited during the early Holocene pluvial period.

Incidentally, only relatively minor climatic fluctuations would required to erode these colluvial deposits once they were ablished. Gile (1975) has dated at least five major Holocene uvial events in New Mexico. Human occupation sites contain- charcoal were found near stream beds that were subsequently ındated with alluvium. He used radiocarbon to date events at 00, 2,100, 2,800, 4,000 and 7,500 B.P. In general, these depos- were associated with pluvial events following warm, dry peri- s that "could have reduced the vegetative cover enough that sion started in particularly susceptible areas" (p. 344). Once luvial deposits have formed, relatively minor fluctuations in nate may result in renewed soil erosion. This phenomenon is ticularly characteristic of the arid parts of the western states, luding the Sierra Nevada foothills. A cooler, more humid nate during glacial times would have promoted vegetation t would prevent significant erosion and thus enable the devel- nent of the Foothills paleosol.

Age of the Foothills Paleosol

The evidence for a "drought" at 11,000 B.P. and the radiocar- ı date of 9,130 B.P. for the alluvium–colluvium at Bayley use, along with the evidence for a pluvial period at about the ne time, all indicate that the colluviation of the foothills may e been a unique event. To put this occurrence into perspec- , we need to evaluate climatic changes over a longer time n. Constant fluctuations in global temperatures are the rule, the exception (Hays, Imbrie, and Shackleton, 1976).

)xygen isotope measurements have enabled Shackleton and lyke (1973) to prepare a tentative sea level curve that reflects relative intensity of these climatic changes (Figure 3). In- ıses in sea level, of course, reflect melting of glacial ice and reases reflect its formation. In general, sea level changes have n gradual except for the abrupt ending of the Wisconsin and ıoian glaciations at about 11,000 and 130,000 B.P., respec- ly. Overall, the rise in sea level following the Tioga recession r 17,000 B.P. was about three times the rise in sea level owing the Tahoe recession after 75,000 B.P. (Figure 3). Even e significantly, the rate of sea level rise was about ten times apid for the Tioga recession (1 cm/yr). The rate was about n/yr between 9,500 and 8,000 B.P., according to data from Francisco Bay (Atwater, Hedel, and Helley, 1977, p. 11). doubt this extremely rapid rise in sea level was related to the ıatic developments that produced the early Holocene pluvial od. Whether or not there was a similar pluvial period and uviation after the Illinoian is unclear, but presumably a col- al unit produced at that time would have weathered to clayey osol during the 9,000 to 130,000 B.P. interval.

hese data reveal no significant manifestations of the climatic ıges that probably occurred during the early and middle consin. Martin and Mehringer (1965, p. 436), speaking of Tahoe recession, observe that, "Despite major fluctuations in ice margin, presumably accompanied by climatic changes would be felt in arid regions, there was no warm interval ıng the last 70,000 years that could be considered as a true interglacial." It appears that the mid–Wisconsin warming trend did not produce the vegetative and climatic changes needed for extensive colluviation in the foothills.

Data and interpretations of the fine structure of climatic change during the last 100,000 years is in a state of flux, especially with the new capabilities that extend reliable radiocarbon dating to 100,000 B.P. (Grootes, 1978; Stuiver, Heusser, and Yang, 1978). Early results obtained with the new techniques for radiocarbon dating confirm that during the last hundred thousand years, there was never a cold–to–warm change that was as abrupt and as extensive as the one at 11,000 B.P. (Grootes, 1978, p. 14).

There is also some question about the widely accepted Sangamon interglacial. Woillard's work (1978, p. 18) in Europe shows that the Sangamon period from 75,000 to 130,000 B.P. actually had three interglacials separated by two intervening glacials. Richmond (1972), working in the Rocky Mountains, drew similar conclusions about the Sangamon period. What effect such cyclic climatic behavior would have had on the development of the Foothills paleosol is still a matter of conjecture. However, it does seem clear from the above cited studies that the concept of soil development during long interglacial periods, followed by colluviation during glacial periods is certainly in doubt for the Sierra Nevada foothills. If one were to ignore the Woillard and Richmond data and continue to accept the concept, the period of landscape stability would encompass only the Sangamon period between the Wisconsin and Illinoian glaciations. This was from about 130,000 B.P. to about 75,000 B.P.—only 55,000 years—which is about as much time as has elapsed since the beginning of the Wisconsin. Nowhere within the Foothills colluvium do we find soil development that would indicate that any part of the colluvium has been exposed an amount of time equivalent to that for the paleosol.

The overall soil development pattern in the foothills is consistent in one major respect. A weak, poorly developed colluvial soil overlies a relatively well developed paleosol. The intensity of soil development could very well be ten times as great for the paleosol as for the colluvial soil. This is consistent with a scenario in which the paleosol appears to have been actively developing throughout the interval between 9,000 and 130,000 B.P. As a further check on this conjecture, we must evaluate the type of soil development that could be expected for Holocene soils on colluvium in the foothills.

Soil Formation During the Holocene

In this section we compare soil formation in the colluvium of the foothills with that in Holocene soils developed in a more arid area (New Mexico) and in a more humid area (Wisconsin). The first objective is to show that some argillic horizon development is highly probable for the Foothills colluvium during the last 9,000 years. The second objective is to show that, for such young soils, this development is highly dependent upon the clay content of the parent material. A third objective is to imply that the Foothills colluvium would have *much* more strongly developed soils if the colluvium was older than Holocene.

An arid area (New Mexico)

Gile (1975) studied soil development on several Holocene surfaces of well–documented ages in New Mexico. Annual precipitation in the New Mexico study area is 200 mm, whereas in the Auburn area it is 890 mm. In spite of the low rainfall, Gile (1975, p. 349) describes argillic (clayey B) horizon development in soils as young as 1,000 B.P. For a 4,000 B.P. soil, he cites "prominent coatings of oriented clay on sand grains" (p. 350). He states that "haplargids occur continuously in... materials that may date from about 7,000 yr ago" and that, in general, he sees the development of "fairly distinct argillic horizons in the Holocene" (p. 358).

Finally, Gile (p. 341) shows two adjacent soils (1,000–2,000 B.P., p. 321) in which an argillic (clayey B) horizon is beginning to form in high–gravel material but not in low–gravel material. The implication is that the clay to gravel ratio of the parent material is of primary importance in developing argillic horizons. Thus, assertions that "argillic horizons do not form during the Holocene" apply only to sites with a particular combination of CTPOT (climate, topography, parent material, organisms, and time) conditions. As a general rule, the younger the soil, the more important is the parent material as a factor of soil formation, with inherited clays dominating the result.

A humid area (Wisconsin)

A striking demonstration of the effect of initial clay content on argillic horizon formation occurs in Wisconsin (Photo 1) where the climate is humid and most of the 800 mm of precipitation per year occurs in summer. Even under these conditions, the degree of argillic horizon development is largely dependent upon the amount of loessial silt and clay covering (Gaikawad and Hole, 1965; Allan and Hole, 1968; Borchardt, Hole, and Jackson, 1968; Milfred and Hole, 1970). Significantly, an argillic horizon is absent wherever loess is absent.

Sierra Nevada foothills

The Sierra Nevada foothills are subject to climatic conditions that would produce soil weathering intensity somewhere between that of the desert climate of New Mexico and the humid temperate climate of Wisconsin. Although there are great differences between CTPOT conditions in New Mexico, Wisconsin, and Auburn, California, we would still expect substantial argillic horizon development within Holocene materials of the foothills. This is because almost all Holocene soils in the foothills were developed in colluvial and alluvial units that were eroded from A and B horizons of previous soils. Thus, sufficient clay was usually present in the colluvial and alluvial material for argillic horizon development to take place.

Such is not the case for the low–clay parent materials of the Great Valley (Singer, 1977; Marchand and Allwardt, 1977). Alluvial sediments of the Great Valley are mostly sandy loams derived primarily from glacial abrasion of the Sierran granites. They contain very little clay, least of all, the fine clay (less than 0.08 um) that is translocated easily. Thus, it is not surprising that argillic horizon development is very slow in many Great Valley soils. Holocene soils developed on Great Valley alluvium do not have argillic horizons (Swan and Hanson, 1977, p. A–23). It appears that, in general, argillic horizonation does not occur in the San Joaquin Valley on most surfaces younger than early Wisconsin (Singer, 1977, p. 69 and 50). Even the early Modesto soils (>29,000 B.P., p. 40) have only a "few thin clay films bridging grains and filling pores."

Many of the colluvial soils in the foothills have similar or slightly stronger development than the early Modesto soils of the Great Valley. For example, the 9,000 year old alluvial unit in Bayley House trench 1 has a "dark grayish brown (10YR3/2m)

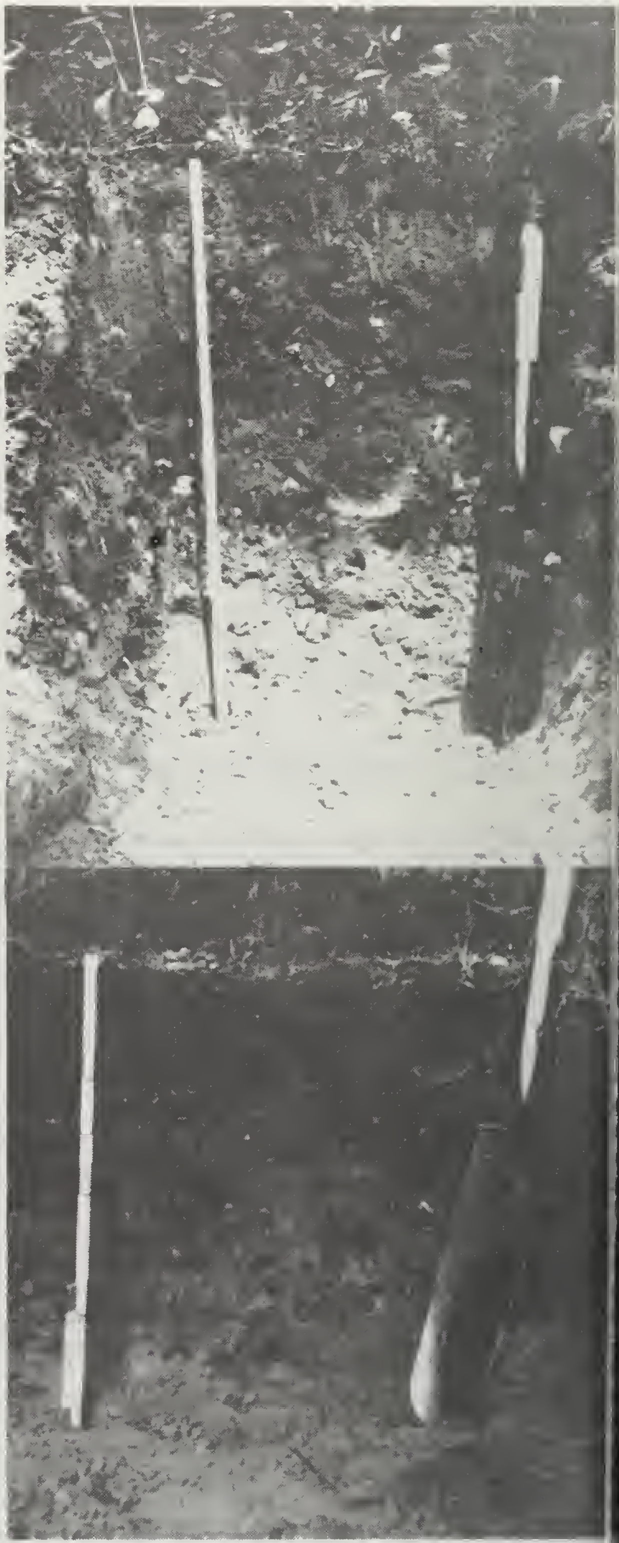


Photo 1. Lapeer loam (top) and Hennepin sandy loam (bottom) illus the effect of clay content of parent material on soil development durin past 12,800 years in Wisconsin. Lapeer loam has a Bt (argillic) horizo cm thick) whereas the Hennepin sandy loam does not. The only signif difference is the incorporation of about 20 cm of silty loess into the L soil. *Photos by Rod Allan.*

ly sandy clay loam" B2 horizon with "well–developed pris-
ic structure," "clay skins on peds", and a "thin weathering
on amphibolite pebbles" (Schwartz and others, 1977, p.
1). Thus, stronger soil development has occurred in the
hills than in the Great Valley in less than a third or a fourth
he time.

nother demonstration of the rapidity of argillic horizon for-
ion as well as the age of the Foothills colluvium was discov-
at the Smith Property site north of Auburn. Although the
venance cannot be completely documented, an artifact
3134, see Photo 13) found in the spoil of the seismic investi-
on trench discussed in a later section, was coated with clay
s that resembled those coating gravel and sand grains in the
uvium and alluvium overlying a paleosol remnant in the
ch. The mano or grinding stone must have been buried at
e depth for it to have accumulated its rather resistant clay
ing. Significantly, the coating survived all the elements dur-
its residence in an Oakland rock garden from May 1977 to
il 1978. Since, according to Martin (1973, p. 973), human
ipation of the area probably did not occur much before
00 B.P., it is possible that the site where the artifact was
d was occupied prior to the major colluvial event we have
othesized for 9,000 B.P. In any case, this artifact clearly
ests a link between the Holocene colluviation and argillic
zonation in the foothills.

Soil Chronology in the Region

addition to differences in clay content of parent materials,
other important consideration has often been omitted from
apts to correlate soils in the Sierras and the Great Valley
those of the foothills. The glacial deposits of the Sierra
ada and the alluvial terrace and fan deposits of the Great
ey have accumulated over long periods of time. Alluvial
for example, are noted for their generally weak develop-
, which is a result of frequent interruptions by flooding and
equent deposition of fresh rock material. Thus, during each
e Sierran glaciations, the soils in the Great Valley were
cted to continuing influxes of glacial flour. These influxes
oubt also contributed to soils on the older terraces via wind
sition, thus adding fresh materials and further complicating
valuation of relative soil development. Likewise, there were
eriods of time when no soil development could occur in the
r Sierra Nevada because of the glacial ice.

ch was not the case for the foothills. Soil formation in the
ills must be considered more or less continuous throughout
Visconsin glaciation. We know that landsurfaces in the Sier-
nd in the Great Valley probably were available for soil
ation for only half that time, perhaps 40,000 years (isotope
s 1 and 3, Hays, Imbrie, and Shackleton, 1976; p. 1131).
fact, along with the low temperatures in the High Sierras
ow rainfall in the Great Valley (400 mm as opposed to 890
t Auburn), would indicate that the intensity of soil weath-
in these areas is less than a fourth of the intensity in the
ills—all of which suggests that the moderate to weak soil
opment within the colluvium of the foothills is consistent
a Holocene age.

casionally, there are indications of two or more colluvial
of different ages overlying the paleosol in the foothills. This
d to some tentative correlations of the lower colluvial unit
soils of similar development on the early Modesto Forma-
f the Great Valley (Swan and Hanson, 1977). The early
sto Formation is at least 29,000 years old — perhaps even
as the onset of Wisconsin glaciation about 75,000 years
. 9). In our opinion, nowhere does the Foothills colluvium exhibit soil development anywhere near as old as 29,000 B.P. This is because the Foothills colluvium is most likely the result of a single erosive eposide during the early Holocene pluvial period about 9,000 years ago.

Even the most advanced soil development within the Foothills colluvium fits a Holocene rather than a Wisconsin age. For example, the soil developed in the fine–grained colluvium above the stoneline in trench ST–68 at the Auburn dam site retained 20 percent clay in the A horizon and accumulated only 32 percent clay in the B (Borchardt, Taylor, and Rice, 1980).

In contrast, the San Joaquin soil in the Sacramento Valley is well developed, having a clayey, prismatic B2t horizon and reddish brown (5YR4/4d) color (Hanson and Begg, 1970, p. 414 and 417). Hanson and Begg consider their date of 103,000 B.P. to be time zero for this soil, though it probably started development somewhat earlier —perhaps at the end of the Illinoian, about 130,000 years ago. The strong development of the San Joaquin soil is in spite of the fact that the present rainfall in the Sacramento Valley is about half that in the Auburn area. At least this degree of development would be expected for early Modesto correlatives in the foothills. The only soil approaching this amount of development in the foothills is the paleosol itself.

Thus it appears that both the Foothills paleosol and the San Joaquin soil were actively developing during the Wisconsin and its preceding interglacial (9,000–130,000 B.P.). Variations in soil development within the colluvium probably reflect soil disturbance as a result of minor colluviation since the initial events of the early Holocene. In addition, variations in the clay and gravel contents of the colluvium would produce variations in soil development. Dated soils in the Great Valley show significant differences in soil development that are dependent upon initial clay contents. For example, the San Joaquin soil has argillic horizon development that closely parallels the amount of clay in the parent material. Hanson and Begg (1970, p. 413–414) describe two sites within a few kilometers of each other. One has a clayey, prismatic B Horizon, while the other has a "less developed" silty clay, angular blocky B horizon. This is presumably a result of soil formation in different parent materials, the first being a clay loam, and the second, a coarser silt loam.

Significantly, the soils developed on the younger Modesto Formation (Wisconsin age) in the San Joaquin Valley "are much more variable in degree of development than soils developed on the older formations" (Janda and Croft, 1967, p. 172). "The occurrence of weak color B horizons and pH differences appears to be more related to the texture of the alluvium (soil parent material) than to the age of the deposit, as the soils formed on finer–textured sandy arkosic alluvium are usually browner than those on coarser–textured alluvium" (p. 173). Obviously, regional soil correlations must consider textural differences of the parent material as being of primary importance. The degree of soil development varies greatly, depending on whether or not fine, translocatable clay is inherited from the parent material. Soils that inherited fine clay will be better developed than soils that had to produce their own clay within the eluvial horizon by weathering.

Pollen Analysis

The discovery of traces of pollen from spruce, hemlock, and other cool weather plants within the Foothills paleosol is significant (Kilbourne, 1978). Such pollen is rare and is well preserved only in those paleosol remnants that were relatively thick, continuous, and reduced. Spruce and hemlock pollen concentrations were greatest within the top part of the paleosol immediately below the colluvium in trenches ST–65 and BHT–66 at the

Auburn dam site. This implies, of course, that the paleosol is the product of soil formation during a culminating glacial period—an obvious contradiction of previous correlations with the pre–Wisconsin interglacial period (Swan and Hanson, 1977; Shlemon, 1977a, 1977b, 1978).

Careful concentration of suitable quantities of uncontaminated pollen from the paleosol may eventually enable a radiocarbon date to be obtained. Newly developed techniques (Van de Graaff accelerators, cyclotrons, lasers, and enrichment devices) require only 1 to 10 mg samples and extend the maximum datable age to 100,000 B.P. (Nelson and others, 1977; Bennett and others, 1977; Grootes, 1978; Stuiver, Heusser, and Yang, 1978; Maugh, 1978).

In the meantime, the pollen data appear supportive of an early Holocene age for the colluvium and a pre–Holocene age for the paleosol. Further evidence to show that the paleosol was an actively developing soil throughout the Wisconsin will be presented.

Relationship between the Foothills colluvium and the paleosol

There is usually very little soil–mixing at the colluvium/paleosol contact. The situation at trench ST–65 along the Maidu East fault zone is rather typical (Photo 2). The stratigraphy of this soil section, described in detail by Shlemon (1977b, p. 14–27; 1978, p. 32–36), can be summarized as follows: A reduced paleosol has formed in Mesozoic amphibolite ahd chlorite schist. This is overlain by an oxidized colluvium derived from well drained soils that developed in the Mehrten Formation on a ten degree slope 36 m toward the west (Frei and others, 1977; Drawing No. 7311). The stoneline at the base of the colluvium represents the deposition resulting from a period of high–energy erosion. This was followed by a slowing in the rate of erosion during which the finer material could remain on the slope. At ST–65, as elsewhere, the stoneline and the colluvium follow the outlines of the topography.

Remarkably little, if any, coarse, colluvially derived material occurs within the paleosol (Table 1). Even though the colluvium/paleosol contact is often very near the surface (that is, w in 30 cm), the two materials are seldom intermingled. In m cases, the oxidized colluvium is still oxidized and the redu paleosol is still reduced. Exceptions occur primarily in th areas that still are poorly drained and presently contain hu gley soils. Even there, many instances occur (BHT–66, to discussed) in which there is little mixing between the colluvi and the paleosol equivalent.

Relationship between climate and paleosol formation

According to pollen data, the Foothills paleosol was acti developing during a climate cooler and wetter than at pres Stratigraphic relations tend to support this also (Figure 4) particular, the spring area to the east of the Geology Buildin the proposed Auburn dam site contains a wealth of informa concerning the recent history of the area. There are artif (mortar and pestals) from Native American occupation, cans, glass, and collapsed excavations from gold mining acti as well as pervasive indications of twentieth century attempt discover the secrets of the Foothills fault system. Happily, s parts of the area remained undisturbed enough for us to sug a possible scenario for the climatic and geomorphic change interest (Figure 4). The details concerning this interpreta are in the sections on trenches BHT–66 and BHT–69 (chardt, Taylor, and Rice, 1980) and ST–64 and BHT–1 (report).

According to this interpretation, the water table has drop since the formation of the paleosol equivalents in each of above mentioned trenches (Figure 4). For example, the pale in ST–64 was formed primarily under reducing conditions, now the paleosol and the Holocene colluvium above it rem relatively well–drained (Photo 3). The water table has not r sufficiently since the deposition of the colluvium to cause changes in colluvium color from red to green. The redu paleosol beneath the oxidized colluvium in ST–64 could possibly have been produced under the present drainage co tions. Of course, other interpretations concerning the reasons

Photo 2. Oxidized Mehrten colluvium over a reduced paleosol developed on Mesozoic rock in a shear of the Maidu East fault zo trench ST–65. The stoneline at the base c colluvium is common throughout the Sierran hills. The knife handle (upper center) is 1 long.

CDMG No.	Parent material	Field No.	Interval sampled cm	Horizon	Total Sand	Total Silt	Total Clay	Sand Very Coarse	Sand Coarse	Sand Medium	Sand Fine	Sand Very fine	Silt Coarse	Silt Medium	Silt Fine	Gravel	Texture	pH *	cos/fs	s/si
					2–0.05	0.05–0.002	0.002	2–1	1–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.02	0.02–0.005	.005–0.002	% > 2mm of whole sample		(paste method)		
					←				Percent of <2mm						→					
SPENCEVILLE																				
196/77	Meta–vol	77B010	81–91	IIB3bg	26.5	45.5	28.0	3.0	3.9	5.2	8.6	5.8	11.1	19.4	15.0	9.3	cl	6.83	0.45	0.58
195/77	″	77B009	183–198	Shear zone	10.0	61.1	28.9	0.2	0.5	1.1	3.2	5.0	13.2	30.1	17.8	2.7	sicl	6.39	0.16	0.17
SMITH PROPERTY Profile No. 1																				
301/77	Collu–vium	77B130	0–48	B2	43.0	35.7	21.3	8.3	8.5	9.2	12.6	4.4	9.7	14.3	11.7	18.7	gl	6.14	0.67	1.20
300/77	Allu–vium	77B129	48–60	IIB3	52.0	24.8	23.2	16.0	14.0	9.0	8.0	5.0	6.4	9.8	8.6	65.9	gscl	6.56	1.75	2.10
298/77	Meta–tuff	77B126	60–72	IIIB21b	21.3	35.5	43.2	3.2	3.5	6.1	4.2	4.3	8.2	13.7	13.6	2.3	c	6.69	0.83	0.60
297/77	″	77B125	72–80	IIIB22b	15.4	45.9	38.7	1.9	1.3	2.8	5.0	4.4	9.4	21.3	15.2	2.4	sicl	6.72	0.26	0.34
299/77	″	77B128	90–100	IIIR1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	rock	6.40	nd	nd
(40 cm to the east)																				
302/77	Meta–tuff	77B131	63–73	IIIB21b	18.9	36.8	44.3	3.2	3.8	3.2	5.0	3.7	7.8	15.1	13.9	5.8	c	6.53	0.76	0.51
(80 cm to the east)																				
303/77	Meta–tuff	77B132	72–80	IIIB22b	28.6	39.1	32.3	3.8	4.0	5.7	8.9	6.2	9.6	16.8	12.7	3.1	cl	6.72	0.45	0.73
(140 cm to the west)																				
296/77	Meta–tuff	77B124	220–230	Shear zone	21.7	44.0	34.3	2.0	2.0	3.4	8.3	6.0	9.1	20.2	14.7	7.1	cl	7.10	0.24	0.49
Profile No. 2 (400 cm to the west of profile no. 1)																				
304/77	Meta–tuff	77B146	25–50	IIIB2b	30.0	39.4	30.6	3.2	3.6	6.4	9.8	7.0	13.0	12.0	14.4	1.2	cl	6.33	0.37	0.76
305/77	″	77B147	61–71	IIIR2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	rock	6.54	nd	nd
HUBBARD ROAD																				
286/77	Meta–tuff	77B097	45–50	East IIB2b	13.1	25.1	61.8	2.5	1.7	2.1	3.5	3.3	4.9	9.7	10.5	6.0	c	4.52	0.49	0.52
287/77	″	77B101	53–58	West IIB2b	12.0	27.2	60.8	1.5	1.5	2.0	3.6	3.4	5.7	10.1	11.4	7.9	c	4.36	0.42	0.44
290/77	Meta–tuff	77B108	40–60	IIB2bg	10.8	34.5	54.7	1.5	1.2	1.5	3.2	3.4	6.0	12.3	16.2	6.1	c	6.61	0.38	0.31
RAILROAD TUNNEL																				
327/77	Meta–Sed	77B165	45–71	IIB2b	13.7	34.1	52.2	0.5	1.5	1.8	5.6	4.3	9.2	13.2	11.7	0	c	5.44	.27	.40
328/77	Meta–Sed	77B166	71–81	IICII	36.1	45.7	18.2	2.0	2.8	8.2	14.2	8.9	16.0	19.2	10.6	0	l	5.28	.20	.79
ST–64 and BHT–1 at AUBURN DAM SITE																				
274/77	Amphi–bolite	77B017	83–97	IIB2b	15.0	26.8	58.2	3.0	2.8	2.0	3.4	3.8	6.6	11.2	9.0	32.4	c	5.24	.82	.56
275/77	″	77B021	120–145	IIB2b	12.6	19.4	68.0	2.1	2.4	2.4	3.3	2.4	4.8	7.8	6.8	2.9	c	5.09	.73	.65
ST–65 at AUBURN DAM SITE																				
307/77	Amphi–bolite	77B159	75–100	IIIB2bg	12.4	39.0	48.6	2.3	1.9	2.0	3.1	3.1	7.2	18.3	13.5	1.4	sic	6.05	.61	.32
308/77	″	77B160	100–135	IIIB3bg	10.0	59.0	31.0	0.5	0.4	1.0	2.7	5.4	13.2	27.0	18.8	0	sicl	6.21	.15	.17
309/77	″	77B161	145–155	IIIR	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	rock	6.68	nd	nd
THE KNOLLS																				
320/77	Talc–Schist	77B163	55–65	IIIB2b	23.2	37.1	39.7	3.2	3.0	4.0	6.6	6.4	12.0	13.6	11.5	6.5	sl	5.47	.46	.63
321/77	″	77B164	65–80	IIIR1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	rock	5.76	nd	nd

*pH of crushed bedrock: 288/77, 4.44; 289/77, 4.86, nd=not determined, cos/fs = coarse sand content divided by fine sand content, s/si = sand content divided by silt content.

Photo 3. Excellent example of a paleosol in tre
ST–64 near the proposed Auburn dam. Meso
bedrock below, Mehrten–derived colluvium ob

this change in drainage might involve erosion of new drainage ways, etc. that could have produced a similar result at anytime in the past (Photo 4). The paleosol in ST–64 is only a fragment; there is no continuous, direct link between ST–64 and BHT–66 (Figure 4). Furthermore, the irregular nature of soil distribution patterns in water barriers, such as this, makes interpretation difficult as seen in the next section.

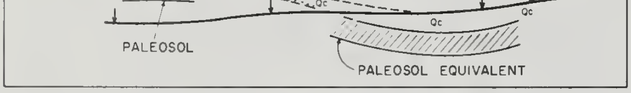


Figure 4. Hypothetical changes in the water table and topography at trenches ST–64 and BHT–66 resulting from climatic change since the last glacial maximum.

At BHT–66, what was probably a small pond during the Wisconsin is now covered with previously–oxidized colluvium which has been reduced, forming a youthful humic gley soil (Borchardt, Taylor, and Rice, 1980). Other evidence of a probable drop in the water table abounds in nearby trench BHT–69. Here, manganese oxide coats Mehrten cobble, and goethite now invades smectitic clays once formed under saturated conditions.

Elsewhere in the foothills, there are indications of a lowering of the water table since the formation of the paleosol. For example, at the Luneman Road site, the upslope portions of the c
luvium overlying the reduced paleosol are still fairly w
oxidized, while the downslope portions are reduced (Schwa
and others, 1977, p. A–73). In the upslope area, late Holoc
colluvial movements do not appear to involve the colluviu
paleosol contact, for an oxidized stoneline is sometimes pres
at the base of the colluvium. Furthermore, the oxidation/red
tion boundary is usually abrupt and coincident with this cont
Thus, the landscape position occupied by the upper portion
humic gley soil during the Wisconsin are now occupied by
dized early Holocene colluvium.

There is no question that the climate during the late Wiscor
was cooler than today. Whether or not there was more precip
tion is still a matter of some debate. Brakenridge (1978),
instance, argues that it was simply cooler and that evapo–tı
spiration was less than at present, but precipitation was the sa
Most accept the conventional opinion that the climate was
ter as well. Stout (1977) dated a concentration of massive la
slides in southern California at ages between 16,000 and 20,
B.P., the glacial maximum. Tree ring data indicated that p
growth near the La Brea tar pits benefited during this per
Stout concluded that precipitation in southern California t
was two to five times what it is today. The data on paleosol
the foothills seems to support a similar conclusion for nort
California as well.

Water Barriers

The formation and preservation of most paleosols in the S
ran foothills is intimately related to the drainage situation wi
water barriers. Such barriers to water movement occur a
faults and geologic contacts. The soils at these localities var
character over extremely short distances because of the
nounced effect of restricted water movement on their forma
(Photo 5).

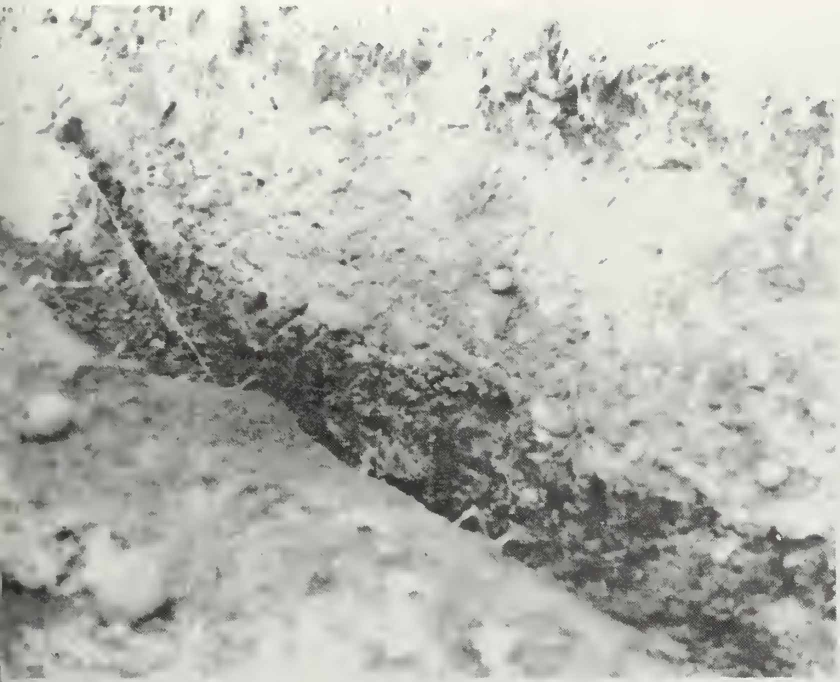


Photo 4. Crescent–shaped paleosol in trench BHT –1 a few meters from trench ST–64 at the proposed Auburn dam. The crescent shape appears to conform to the paleo–surface of an old gully or small basin.

o 5. Oxidized soil overlying a grayish, re-
d Bg horizon on the right side and an oxi-
d R horizon on the left side of the water
er in the center of the photo. Water still col-
c in this trench to the new level of the partially
vated barrier. Luneman Road site, 20 m from
end of trench No. 3. The trench shore is 20
wide.

"Pseudopaleosols"

The effects of water movement were especially obvious in soil features along the Maidu East fault zone near the proposed Auburn dam (Shlemon, 1977a; Borchardt, Taylor, and Rice, 1980). Here, the movement of water through fissures in the Mehrten Formation first deposited or formed a clay mineral, halloysite, that forms from feldspar. The formation and deposition of this clay tended to gradually restrict water movement, developing in effect a perched water table in many places within the fault zone. Under these conditions of poor drainage, montmorillonite formed from volcanic glass in addition to the halloysite that continued to form from feldspar. Vertical and horizontal drainage within these fissures was irregular; as a result, the configurations of the resulting soil tongues or "pseudopaleosols" were irregular (Photo 6). "Pseudopaleosols" are similar to many paleosols in that they are gray or olive green in color, indicating that the iron within them is in the reduced form. They appear to be moist all year long and are invariably accompanied by numerous roots that penetrate as much as 13 meters beneath the surface. In configuration the "pseudopaleosols" conform to the present topography and drainage patterns (Photo 7). Thus, these gleyed areas are forming contemporaneously and probably have variable ages that range up to and perhaps beyond those of the Foothills paleosol.

Vegetation

Water barriers often produce springs or show a pronounced expression in the growth of vegetation (Photo 8). In such areas, the flow of water is blocked or slowed when it encounters less permeable rock. The water level then rises until it flows around or over the barrier (Photo 5).

Soil formation

The soils formed in these gray or gleyed (Soil Survey Sta 1975) areas (Photo 5) associated with water barriers often co tain expansive clay minerals such as smectite. These minerals a relatively unstable in most well–drained soils, and the presen or absence of smectite can often reveal the history of a so Unfortunately, the situation can be complicated by the presen of micaceous minerals in the parent rocks. Mica and chlorite a abundant in many of the Mesozoic rocks along the Foothi fault system. Even in well–drained soils, micas can be tran formed to vermiculite (Kittrick, 1973) and then to smect (Borchardt, 1977a; p. 309). This process is accelerated throu leaching of potassium by rainfall or uptake by plants. On t relatively mica–free Tertiary Mehrten Formation, the presen of montmorillonite (a smectite mineral) indicates that it form from solution under poor drainage conditions (Borchardt, Ta lor, and Rice, 1980). On the other hand, smectite can form und both good and poor drainage in micaceous Mesozoic rocks.

As seen for the Mehrten Formation, the drainage patter involving water barriers in the Mesozoic bedrock can be e tremely complex. This complexity is seen commonly during t dry season when the distribution of humic gley soils is reflect in irregular vegetation patterns (Photo 8). Perched water alo faults and geologic contacts does not necessarily collect only the uphill side. An interesting visual example of this irregulari of water movement can be seen at the foundation for the rig abutment of the proposed Auburn dam (Photo 9). This anal gous, though artificial situation, illustrates how water mov along the surface of the concrete until it encounters a barrier a then pours over or around it. If soils formed in these areas th would be saturated with water a large portion of the year, a would tend to be gray in color and have the characteristics humic gley soils. Water can accumulate on either the uphill

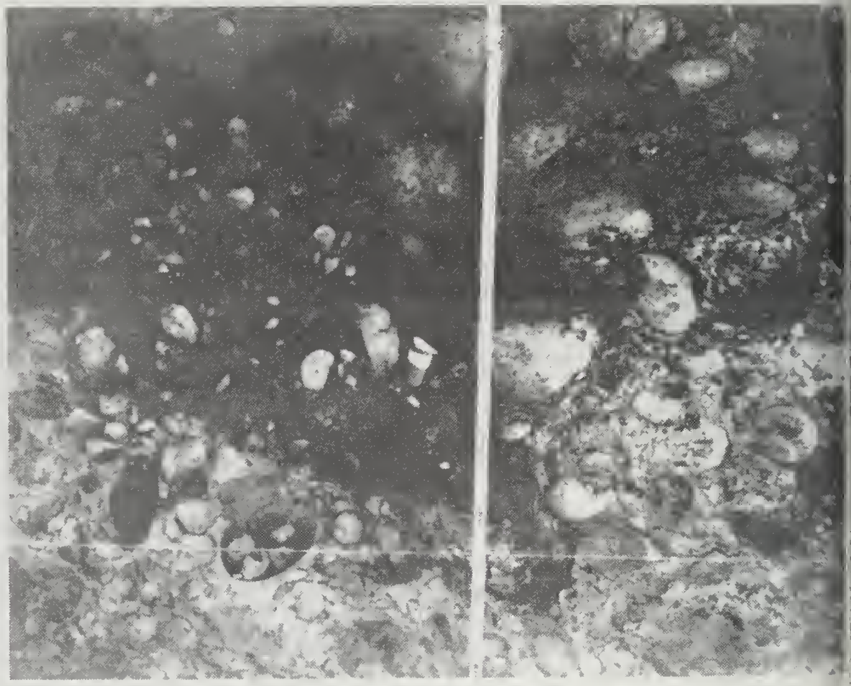


Photo 6. "Pseudopaleosol" occurring beneath the oxidized soil developed on the Mehrten Formation in trench BHT–111. The Maidu East fault zone is responsible for the drainage conditions that produced the halloysite and montmorillonite clays in this feature. Scale in cm.

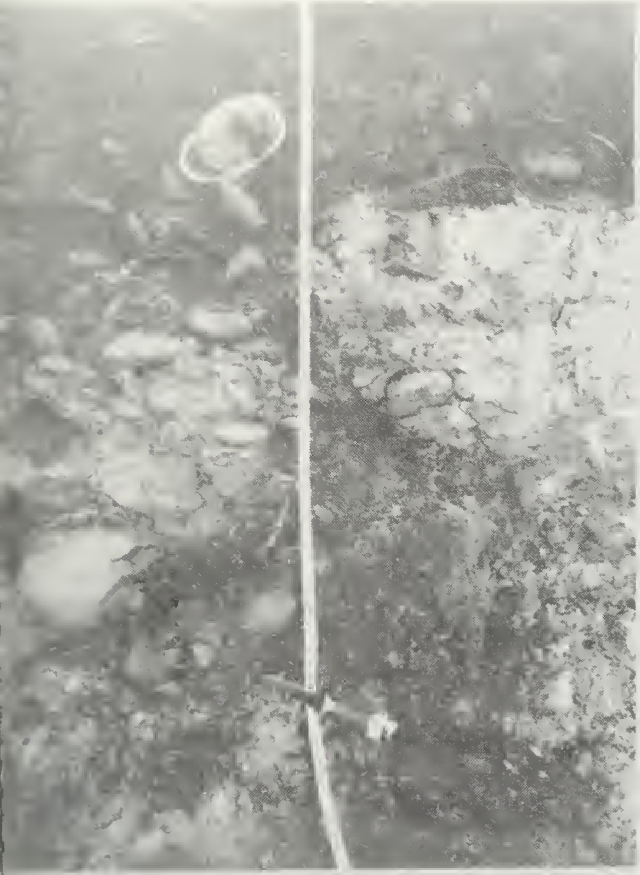


Photo 7. "Pseudopaleosol" overlain by consolidated Mehrten conglomerate in trench GT–1. The perched water table at this site causes the "pseudopaleosol" to develop vertically within the Maidu East shear and laterally along the contact between the Tertiary Mehrten Formation and the Mesozoic granite beneath. Scale in cm.

8. The Luneman Road site just north of The
site shows the relatively lush vegetation
ng wherever the water table approaches the
e within the fault zone. The spring in the
r of the photo is used to water cattle, and the
lar surface of the soil reflects the influence
ttle and moisture changes on the expansive
that form in such poorly drained areas. View
king north.

Photo 9. Foundation and "dental work" of the right abutment of the proposed Auburn dam. Water seepage appears to originate from a barrie produced by T–25, a talc zone that traverses the extreme upper part of the abutment. A shear in the Maidu East fault zone cuts the Tertiary Mehrten Formation about 150 m upslope from the end of the abutment (Frei and others, 1977, p. 39, Drawing Nos. 7302, 7324 and 7360).

downhill side of a barrier depending upon the configuration of the barrier and the relative permeability of the water–carrying materials. If this example were a natural geologic situation, the soils in the wet areas would contain expansive clay and be more resistant to erosion than the oxidized soils in the drier areas. The observed irregularity and local variety of near–surface water distribution appear to account for much of the irregularity of location and stage of preservation of paleosols overlying the Foothills fault system.

EVALUATION OF FAULT FEATURES AND PALEOSOLS

The objectives and the thoroughness of studies conducted at each of the paleosol sites (Table 2, Figure 1) vary depending upon the features observed. No two sites are identical, just as no two trench faces are ever identical. Even so, the similarities were sufficient for a general pattern to emerge as a result of field observations and laboratory data. As implied in the previous sections, this pattern supports the hypothesis of a Holocene age for the foothills colluvium and a Wisconsin age for the paleosol

Because the paleosol may have been an active soil during the period from 9,000 to 130,000 B.P., the tectonic features preserved within it are often difficult to interpret. For example, an irregular paleosol thickness may result either from differentia rates of weathering in widely varying rock types common in faul zones, or from continuing soil formation after tectonic movements. Certain tectonic features, such as slickensides, would be destroyed during active soil formation. Presumably, these would be preserved in the paleosol only at depths greater than the zone of active pedoturbation. Where pedoturbation now is confined to the Holocene colluvium, slickensides in the paleosol beneath may indicate Holocene fault movement.

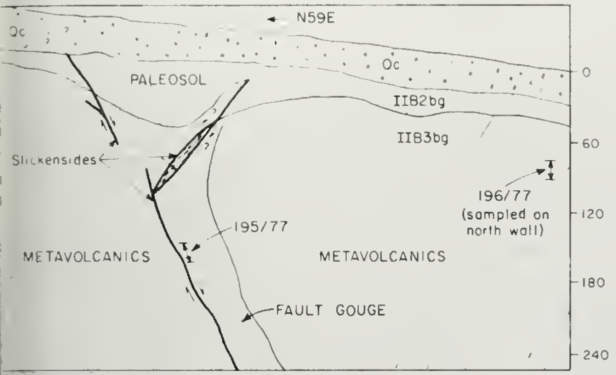
Spenceville

The Spenceville site is the northernmost of those studied being 31.5 km NW of the proposed Auburn dam (Figure 1 Table 2). Only two samples were taken from trench No. 1a which has been evaluated in detail by Schwartz and other

Table 2. Paleosol localities evaluated during this study.

Locality name	*Latitude*		*Longitude*		*Distance and direction from the proposed Auburn dam*	
	deg.	*min.*	*deg.*	*min.*	*km*	
Spenceville	39	06.05	121	17.20	31.5	NW
Smith property	39	04.98	121	05.57	23.2	N
Hubbard Road	38	57.79	121	07.85	11.0	NW
Railroad Tunnel	38	53.54	121	04.87	2.0	NW
ST–64 & BHT–1 at the Auburn Dam Site	38	52.30	121	03.75	0.3	S
ST–65 at the Auburn Dam Site	38	52.28	121	03,80	0.6	S
The Knolls	38	45.56	120	57.17	15.3	SW

1977, p. A–192). One was from a clay–filled fissure beneath the aleosol, and the other was from within the fault gouge beneath he soil tongue that occurs immediately above what may be the nost recent fault break (Figure 5, Photo 10). A comparable soil ongue in a different shear in a trench to the north was analyzed n detail (Photo 11).



gure 5. Sketch of the south wall of trench 1a showing the primary fault ature at the Spenceville locality (modified from Schwartz and others, 1977, gure 27).

Schwartz and others (1977) conclude that the continuity of ie paleosol in trench 1a has been disrupted by soil movement. here is some question as to whether or not this resulted from ectoturbation" (soil disturbance resulting from tectonic move- ent) or from natural, seasonal soil expansion and contraction ue to variation in moisture content. Strong arguments favoring ctoturbation include the fact that the slickensided fault plane ppears contiguous with slickensides that continue on either side the soil tongue (Photo 10). These slickensides continue up to e colluvium and have been observed extending into the colluvi- n on the north wall of this trench, although the colluvium– leosol contact is not displaced (Schwartz and others, 1977, pp. –194 and A–200). Incipient columnar structures within the paleosol remain vertically oriented in spite of movement along the diagonally slickensided plane (Photo 10). Thus, visual observation appears to rule out downslope creep or micro–landslide activity as being responsible for the slickensides.

Another possible explanation for the apparent shearing on either side of the soil tongue involves soil expansion and contraction. Seasonal changes in moisture cause soils containing expansive clays to shrink and swell. As mentioned previously, such clays are common within the poorly drained micro–environments associated with faults. Expansive clays are indicated wherever soils form shrinkage cracks upon drying. Cracks of this type appeared in the upper, V–shaped part of the soil tongue after the trench had been exposed to dry summer air for several weeks (Photo 10). Under natural conditions, the upper, V–shaped part of the soil tongue may have shrunk enmass. Subsequent re–expansion enmass then might have produced the diagonal slickensides. This explanation might be plausible for slickensides bounded by non–expansive bedrock on one side, but it becomes doubtful for those bounded by expansive clay on either side (Figure 5). If soil expansion is responsible for these slickensides in the manner just described, the phenomenon appears to be unique. Soil tongues containing expansive clays are rather common above faults, but we are unaware of any others bounded by slickensides that are not also associated with tectonic slickensides at depth.

Particle size distribution

The two samples from trench No. 1a at Spenceville were similar in that they had nearly equal but surprisingly low clay contents (28 percent, Table 1). The pH was between 6.4 and 6.8, which is similar to that of the humic gley horizons in the Mehrten Formation near the proposed Auburn dam (Borchardt, Taylor, and Rice, 1980).

The most striking difference between the samples was the high silt content of the fault gouge—61 percent, more than double the amount of clay. The silt content of the paleosol sample was 46 percent, and it had 2.5 times as much sand as the sample from

oto 10. Diagonal slickensides in the paleosol d along either side of the soil tongue in trench at the Spenceville site.

the sheared area. Significantly, the percentages in each of the subdivisions within the sand and silt fractions of the sample from the shear zone increase with each decrease in particle size until a maximum is reached in the medium silt fraction (Table 1). This progression is probably a result of shearing and crushing within the fault zone. Abrasion of large particles produces medium size particles. Abrasion of medium size particles produces fine partices, in a continuing progression until some minimum size is produced for the existing rock type and shearing conditions. This sort of progression does not hold for unsheared material.

For example, the paleosol sample (CDMG No. 196/77) collected outside the gouge zone had a very fine sand content (5.8 percent) which was less than the contents in adjacent fine sand (8.6 percent) and coarse silt (11.1 percent) fractions (Table 1). This type of analysis shows promise for distinguishing between gouge and non-gouge materials in future studies.

Clay mineralogy

The clay fraction from the paleosol had abundant montmorillonite and moderate vermiculite contents, while the shear zone had only montmorillonite (Table 3). Normally, montmorillonitic soil derived from a micaceous rock would be considered more weathered than one containing vermiculite. This is because mica weathers according to the following equation (Borchardt, 1977a, pp. 312 and 309):

$$\text{mica} \rightarrow \text{vermiculite} \rightarrow \text{montmorillonite}.$$

This reaction emphasizes the fact that soil weathering tends to remove potassium and tetrahedral aluminum from inherited layer silicates. In addition, montmorillonite can form under conditions which produce solutions high in silica and nearly neutral in pH—conditions that are present at this site. On the other hand, vermiculite can form only from mica. Thus, a detailed analysis of bedrock and soil variability in regard to mica, vermiculite and montmorillonite contents, along with particle size distribution analyses, might show how much of the soil tongue was a result of weathering and how much was the result of tectoturbation. The extent of the mixing of colluvium, paleosol, and weathered fault gouge within the soil tongue might give some idea of the age relationships among these features.

Ca/Fe ratios in a soil tongue in the northernmost trench

A comparable soil tongue (Photo 11) was observed in a more recent trench north of trench No. 1a. Slickensides along a fault plane extend to within 80 or 90 cm of the surface. The boundary between the modern, oxidized soil and the reduced soil tongue has a peculiar 15–cm step at the 55 and 70 cm depth interval (Photo 11). A detailed sampling program was undertaken to evaluate the nature of this boundary.

Ca/Fe ratios of less than 420 um soil are plotted on Photo 11. Ca/Fe ratios of the paleosol or soil tongue range between 0.19 and 0.22 (Photo 11). The colluvially-derived A1 horizon of the modern soil had values of 0.32 and 0.29, with the B horizon having intermediate values between 0.23 and 0.27, probably as a result of mixing of paleosol and colluvium. Normally, Ca/Fe ratios decrease with nearness to the surface as Ca leaches and Fe accumulates as a result of weathering. This may reach a temporary plateau as seen for the paleosol (Photo 11) and for a soil at trench BHT–53 on the Mehrten Formation (Borchardt, Taylor, and Rice, 1980). The unweathered Mehrten Formation had a Ca/Fe ratio of about 0.60, wheras the soil above it had ratios of about 0.20 unchanging with depth except for values between 0.31 and 0.43 in the upper 20 cm. The enrichment in surface horizons commonly results from recycling of calcium from decaying plant litter. Colluvial deposition of fresh bedrock fragments also may contribute to Ca–enrichment. In the Spenceville soil, the Ca/Fe variations were a result of variations in Ca concentration (Figure 6), with Fe being relatively uniform even though oxidative states vary from horizon to horizon (Photo 11).

The overthickening of the B2 horizon on the west side of the step is not simply a result of offset in the B2 followed by colluvial deposition at the ground surface. If this were the case, the Ca/Fe ratios of 0.25 and 0.27 and the Ca percentages of 1.88 and 1.91 that occur on the east side of the step at 50 cm also would occur at 60 cm on the west side of the step (Figure 6, Photo 11). Instead, these values remain confined to the 50 cm level on both sides of the step. The general increase in Ca content with nearness to the surface may be a result of leaching from the relatively Ca–rich A1 horizon. The transition between the B2 and 11B2bg horizons is more abrupt on the east than on the west. Ca accumulates to greater depths on the west than the east. Likewise, the Ca accumulation is coincident with the improved drainage indicated by the oxidation of iron within the area immediately above the fault plane (Photo 11). Thus, the preferential movement of water toward the fault plane could produce these results (Figure 6).

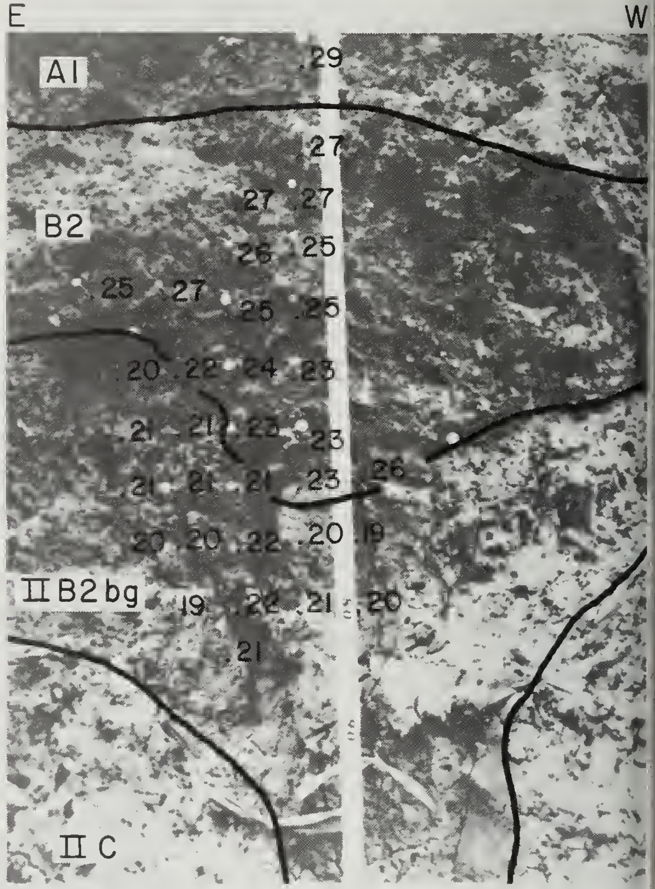


Photo 11. Fault feature in the south wall of the northernmost trench at the Spenceville site. Tectonic slickensides are within a meter of the soil surface, and the soil/paleosol contact is irregular, forming a step–like feature at 60 cm. The smaller nails represent sampling sites. Data points are Ca/Fe ratios.

CDMG No.	Parent material	Field No.	sampled cm	Horizon	XRD Peak /background[1]							
					C	C/B	B	C	F	D	A	D
					St	Bd	Mt	Vr	Ch	Kl	Mi	Talc
					17A	17A	18A	14A	14A	7.2A	10A	9.2A
SPENCEVILLE												
196/77	Meta-vol	77B010	81–91	IIB3bg	0.88		0.75	0.27				
195/77	"	77B009	183–198	Shear zone	1.12							
SMITH PROPERTY Profile No. 1												
301/77	Colluvium	77B130	0–48	B2				0.53	0.12	0.31		0.15
300/77	Alluvium	77B129	48–60	IIB3	0.21	0.21		0.85		0.48	0.11	0.13
298/77	Meta-tuff	77B126	60–72	IIIB21b	1.00			0.43				0.44
297/77	"	77B125	72–80	IIIB22b	1.18		0.65	0.65				0.83
299/77	"	77B128	90–100	IIIRI	0.90	0.90		0.60				0.31
(40 cm to the East)												
302/77	"	77B131	63–73	IIIB21b			0.71					0.41
(80 cm to the East)												
303/77	"	77B132	72–80	IIIB22b				0.41				0.37
(140 cm to the West)												
296/77	Meta-tuff	77B124	220–230	Shear zone			0.89					
Profile No. 2 (400 cm to the west of profile no. 1)												
304/77	"	77B146	25–50	IIIB2b	0.90		0.89	1.60				
305/77	"	77B147	61–71	IIIR2	0.65	0.65		0.70				
HUBBARD ROAD												
286/77	Meta-tuff	77B097	45–50	East IIB2bt	0.46	0.46		0.38		0.52		
287/77	"	77B101	53–58	West IIB2bt	0.77	0.54	0.13	0.40		0.57		
288/77	"	77B104		East IIR1	0.68	0.38	0.30	0.26		0.30		
289/77	"	77B105		West IIR2	nd	0.15	0.57	0.28			0.35	
290/77	"	77B108	40–60	IIB2bg	0.82	0.49	0.52			0.28		
RAILROAD TUNNEL												
327/77	Meta-Sed	77B165	45–71	IIB2b	1.11	0.66*	0.45	0.61		0.22		
328/77	Meta-Sed	77B166	71–81	IIC11	0.97	0.97				0.20		
ST–64 and BHT–1 at AUBURN DAM SITE												
274/77	Amphibolite	77B017	83–97	IIB2b	0.43	0.07*	0.36	0.28		0.91		
273/77	"	77B016	127–137	IIC			0.22	0.64		0.26		
275/77	"	77B021	120–145	IIB2b	0.96	0.48*	0.48	0.31		0.56		
ST–65 at AUBURN DAM SITE												
307/77	Amphibolite–chlorite schist	77B159	75–100	IIIB2bg	0.59		0.61	0.14	0.38			
308/77	"	77B160	100–135	IIIB3bg	0.65		0.82	0.72	0.48			
309/77	"	77B161	145–155	IIIC	0.47	0.17*	0.30	0.81*	0.81		0.28	
THE KNOLLS												
320/77	Talc-schist	77B163	55–65	IIIB2b	0.70	0.70*		0.61*	0.41			1.23
321/77	"	77B164	65–80	IIIR1	1.05	1.05*		0.85				3.06

*Calculated, not measured.

[1](Peak intensity - background intensity) ÷ background intensity.

A = Mg sat., 54% R. H.; B = Mg sat., glycol; C = Mg sat., ethylene glycol; D = K sat., 110 C; F = K sat., 500 C.

St = smectite, Bd = beidellite, Mt = montmorillonite, Vr = vermiculite, Ch = chlorite, Kl = kaolinite, Mi = mica.

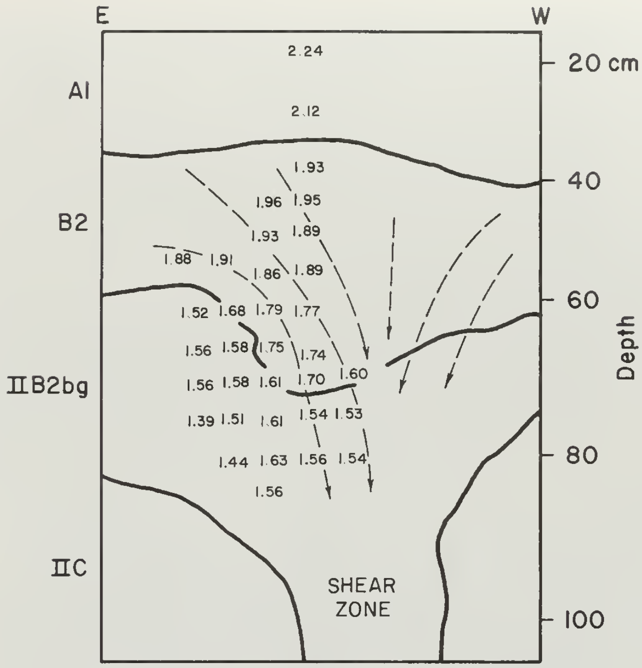


Figure 6. Calcium percentages in samples from the fault feature in Photo 11. Arrows indicate the hypothetical movement of water toward the fault plane.

A similar tendency was observed in trench BHT–53 at the site for the proposed Auburn dam (Borchardt, Taylor, and Rice, 1980). A funnel–shaped area at the top of a soil tongue overlying a shear in the Maidu East fault zone had a mottled appearance indicating that the water table had its greatest fluctuations directly over the shear. The present–day oxidation of features (such as soil tongues) that were formed under reducing conditions implies either an improvement in drainage or a reduction in effective precipitation (see Strahler and Strahler, 1973, p. 312). As shown previously, a reduction in precipitation since the end of the Pleistocene is highly probable. Thus, certain degradation features of many soil tongues may be a Holocene (interglacial) phenomenon, whereas their formation was primarily a Wisconsin (glacial) phenomenon.

In general, the Ca/Fe data confirm the visual observations indicating a step-like soil/paleosol boundary in the northernmost trench. However, slickensides within the soil tongue are not directly coincident with this apparent step in the paleosol. Likewise, the Ca/Fe ratios and the calcium percentages can be interpreted as a result of increased aridity since the formation of the soil tongue. Consequently, the step-like feature in the northernmost trench at Spenceville is not necessarily tectonic in origin.

Summary

Slickensides on either side of a soil tongue indicate possible Holocene soil movement at the Spenceville site. This movement appears to be a result of tectonism, though other phenomena involving expansion and contraction cannot be ruled out. The clay fraction from the fault gouge beneath the soil tongue contains montmorillonite, and the IIB3bg horizon of an adjacent paleosol contains vermiculite as well as montmorillonite. These are both expansive clays which may have contributed significantly to the formation of the slickensides.

An apparent offset in a comparable soil tongue in northernmost trench may be a result of irregular soil devel ment during the Holocene. Ca/Fe ratios confirmed the visi observations of increased iron oxidation resulting from a possi decline in precipitation since the original development of the s tongue.

Smith Property

The Smith Property is located on the highway 49 lineam 23.2 km north of the proposed Auburn dam (Figure 1; A Schwartz, and McCrumb, 1977, p. B–1 to B–26; Schwartz a others, 1977). The trench across this linement exposes a we ward dipping shear that has a poorly drained paleosol on its e side and bedrock on the west (Figure 7 and Alt, Schwartz, a McCrumb, 1977, pp. B–11, B–15, B–17). The paleosol (CDM Nos. 297, 298, 302, and 303/77) is overlain by an oxidiz alluvial deposit that fills a gully to the east.

The alluvium (CDMG No. 300/77) gradually decreases thickness until it is only a few centimeters thick near the she eventually grading into a stoneline on the west side of the she The alluvium and the stoneline is overlain by a colluvial u displaying weak soil development (CDMG No. 301/77). T oxidized colluvial unit comprises the modern soil which is brante loam and is classified as a Mollic Haploxèralf develop on diabase according to a recent soil survey report (Brittan a others, 1975, sheet 22, p. 37 and 94).

A close look at the shear plane (Photo 12) reveals a slicke sided surface which we sampled for comparison to the paleos The paleosol is laterally discontinuous in this trench, either b cause of differential erosion or differential soil formation. On t north wall, the paleosol is immediately adjacent to the she (Figure 7 and Alt, Schwartz, and McCrumb 1977, p. B–1

Photo 12. Closeup of the slickensided shear plane that occurs at the dep of 2.3 m at the Smith locality. Field Sample No. 77B124 was analyzed CDMG No. 296/77.

However, on the south wall, the paleosol exists as a simil feature, but this time it is about a half meter to the east of t shear. This corresponds with the direction of the modern drai age and with the general trend of the alluvial–filled gully. Cons quently, there is some possibility that the distribution of paleos fragments is a result of variable drainage across the geolog contacts and faults in the area. The juxtaposition of the paleos against the relatively unweathered bedrock on the other side of he shear would then be a fortuitous occurrence. This simply may have been the path of least resistance for drainage around a resistant outcrop much older in age than the paleosol. The unweathered remains of this outcrop on the west side of the hear are now covered by colluvium. Thus, considerable erosion must have occurred in order to remove the original weathered veneer from the former outcrop. Alternatively, continued fault movement may have thrust this fresh rock against the weathered paleosol.

Sampling program

Our sampling program (Figure 7) was designed to help answer the following questions: (1) Are the physical and mineralogical characteristics of the paleosol consistent with *in situ* formation from bedrock? (2) What is the nature of the slickensided clay within the shear zone? (3) Is this clay related to the paleosol above it? (4) Were the colluvium and the alluvium derived from the same bedrock types during the same erosive episode?

Particle size analysis

The most obvious difference among the materials sampled at the Smith Property was the gravel content. The colluvial unit had 19 percent while the alluvial unit (or stoneline) beneath it had 66 percent gravel (Table 1). The contact with the paleosol immediately beneath this is extremely abrupt. Only 2 percent gravel was found in both the top and bottom portions of the paleosol in Profile No. 1. Profile No. 2, taken about 4 m to the west of the main shear (Figure 7), had even less.

In the alluvium, the contents of each of the succeeding sand fractions decrease with decreasing size from very coarse to very fine sand (Table 1). This is an indication that the genesis of the alluvium is more closely related to its deposition by running water than to other processes. Pebbles within the alluvium even appear oriented with their long axis parallel to the soil surface (Figure 7). "Pedoturbation" (soil mixing, by plants, animals, or faulting) thus appears to be minimal at this depth of 48 to 60 cm.

The colluvium appears poorly sorted, containing more fine than coarse sand (Table 1). The clay content of a representative

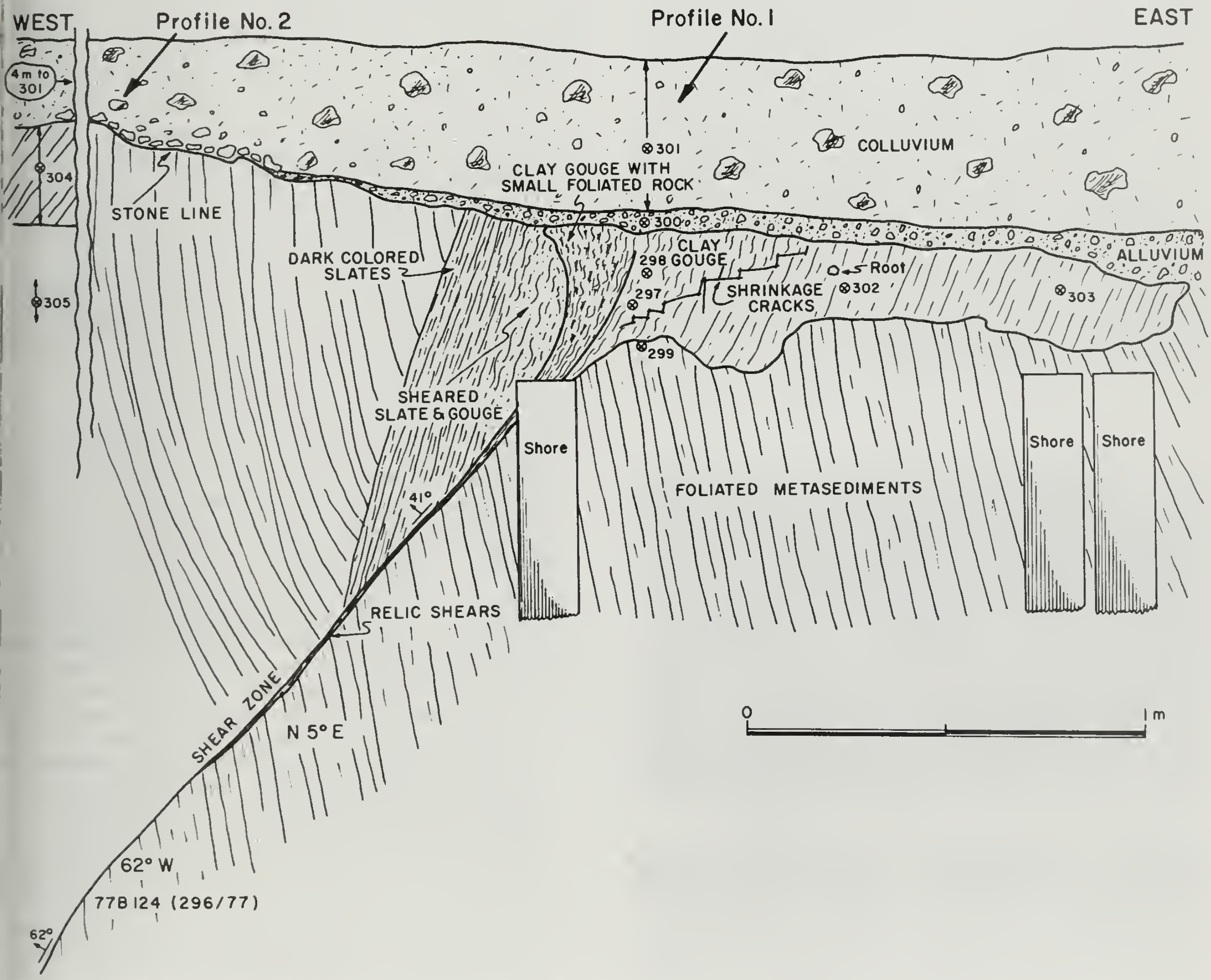


Figure 7. Log of the primary fault feature in the north wall of the northern-most trench at the Smith locality on the Highway 49 lineament.

sample of the colluvium was 21 percent. Some of this clay has illuviated to the alluvial unit where it coats the gravel as "clay skins." The significance of clay skins on the artifact (Photo 13) found at this locality has been discussed earlier. Because two-thirds of the alluvial unit is gravel, the 24.8 percent clay determined for the less than 2 mm fraction represents only 8 percent of the soil. The structure of the alluvial gravels remains porous and is certainly open enough to accommodate further deposition of clay from the colluvium above it. This indicates that the colluvial–alluvial sequence represented by the upper 60 cm of Profile No. 1 is still only in the earliest stages of soil development. An early Holocene age for the sequence is not out of the question.

The paleosol had clay contents between 31 and 44 percent (Table 1). These decreased from 43 to 39 percent when the depth increased by 10 cm (samples 298/77 and 297/77). This trend was confirmed by samples 302/77 and 303/77. These data represent the type of results we expect for the bottom half of a "clay bulge." A clay bulge occurs when a rock weathers to form an A and a B horizon. Clay contents increase with depth to a point somewhere in the middle of the B horizon and then decrease with depth to the bedrock. A more detailed sampling program (2–cm intervals?) could detect the midpoint of such a clay bulge. From this, we could speculate about how thick the paleosol might have been before erosion removed the A horizon and the upper part of the B horizon. In any case, the data support formation of the paleosol primarily *in situ* followed by erosion of the upper B horizon.

The slickensided material within the shear zone had less clay (34 percent, 296/77) than the bottom of the paleosol (39 percent, 297/77) (Table 1). The coarse sand/fine sand (cos/fs) ratios decreased with depth in the paleosol — perhaps indicating the usual effect of surface area on rate of weathering. This is just the opposite of the results for soils on the Mehrten Formation where coarse sand and gravel aggregates tended to breakdown to finer particles as a result of interstitial weathering (Borchardt, Taylor, and Rice, 1980). The cos/fs ratio in the shear zone was 0.24, slightly less than a sample from the base of Profile No. 1 (compare CDMG No. 296/77 and 297/77, Table 1). The particle size data, though similar, are insufficient to prove a gen relationship between the paleosol and the slickensided mate within the shear zone.

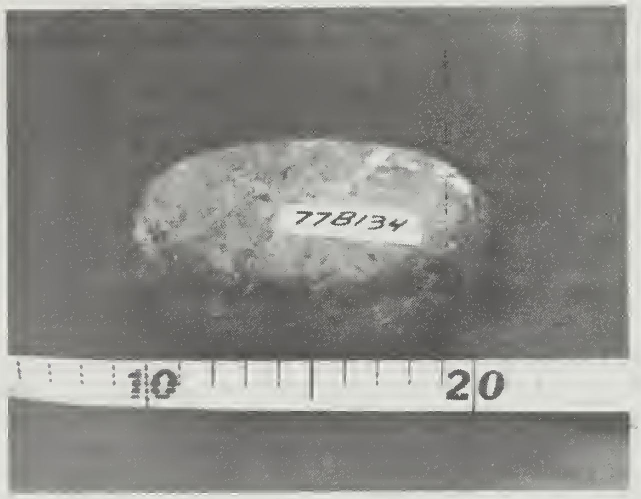


Photo 13. Artifact found in the spoil at the Smith Property site. Although, its provenance cannot be completely documented, this mano or grinding rock is coated with clay skins of the same color as those coating gravel in the colluvium and alluvium overlying the paleosol. Scale in cm.

Clay mineralogy

The mineralogy of the clay fractions (Table 3) may be su marized as follows: (1) talc occurs in the paleosol and bedr on the east side of the fault but not on the west side, (2) talc a occurs in the colluvium and alluvium, (3) the paleosols ha montmorillonite in the B horizons but beidellite in the R ho zons, (4) kaolinite or chlorite occur only in the colluvium a alluvium, (5) there are smectites in the colluvium, (6) beidell occurs in the alluvium, and (7) vermiculite occurs in all sampl Such variable clay mineralogy yields a very complex but possi revealing picture.

Even though talc is present in the paleosol on one side of t fault only, similarities between the two sides are evident in t paleosols. The major similarity is the apparent transformation montmorillonite to beidellite. These two smectites form a co tinuous series in which the substitution of A1 for Si in t tetrahedral sheet increases from zero for ideal montmorilloni to a maximum for ideal beidellite (Borchardt, 1977a, Figu 9–7). Of course, tetrahedral substitution occurs especially minerals formed at high temperature. This is because the mo rapid ionic motions that occur during high temperature form tion allow for greater discrepancies in the sizes of the substitut ions. At atmospheric temperature and pressure, tetrahedral A becomes unstable and tends to be replaced by Si (Borchar 1977a, p. 309). Beidellite is classified as a smectite mineral wi greater than 50 percent of its negative charge produced by te rahedral A1. A smectite with 49 percent of its charge in t tetrahedral sheet is thus a montmorillonite. Theoretically, on a small amount of A1 need be replaced by Si in order to tran form beidellite into montmorillonite. Thus, the transformati does not necessarily indicate any great amount of weatherin Likewise, we don't know exactly how the test (Harward an Brindley, 1964) used to distinguish between beidellite and mon morillonite reflects this theoretical classification.

The clay in the shear zone at the 220 to 230 cm depth co tained predominantly montmorillonite with minor vermiculi (CDMG No. 296/77, Table 3). Talc was absent, and thus th slickensided clay owes its origin to the alteration of talc/fr bedrock on the west side of the shear. This fact answers th question posed earlier in regard to the relationship between th paleosol on the east side of the shear and the clay in the shea zone. They are clearly derived from two different materials.

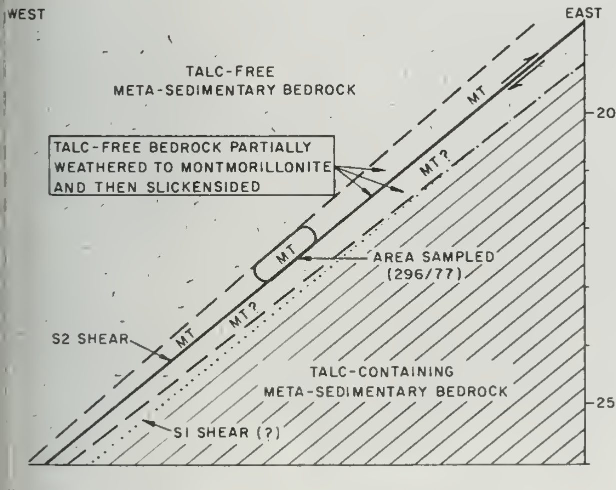
Talc is rare in soils; its presence in San Pablo Bay, Californi is one of the few reported occurrences (Zelazny and Calhou 1977, p. 452). "In soils (talc) forms an inert constituent" (Bur 1927, p. 61). Therefore, in this unique situation talc can b considered residual from the parent material. A detailed stud of its quantitative variability in the parent rocks and its enric ment in paleosol horizons relative to less resistant minera would help determine the intensity and duration of weathering

The slickensided clay does not contain talc from the paleos or kaolinite from the colluvium or alluvium (CDMG No. 296 77, Table 3, Figure 8). This indicates that clay in the shear zon probably formed *in situ* rather than having been translocate from the soils above the shear. Apparently, the beidellite in th talc–free bedrock above the contact transformed directly t montmorillonite or else silica, and base concentrations were hig enough to precipitate montmorillonite directly from solution Unfortunately, the clay gouge on the footwall side of the shea (area beneath the knife blade in Photo 12) was not sampled. It physical appearance was identical to that of the material above it, but a detailed analysis of this material as well as a recheck of the bedrock on either side of the shear would be necessary to support the S2 shearing hypothesized in Figure 8. Detailed sampling within the shear zone would be required to thoroughly delineate the contact between the two bedrock types. However, even with this limited data, it appears that the slickensides in the zone were formed subsequent to the pedogenic formation of the montmorillonite, a near–surface phenomenon. The slickensides thus are not simply relicts from shearing during Mesozoic time. They probably result from fault movements that post–date the formation of montmorillonite. In addition, the montmorillonite appears to form more rapidly than the erosive forces can remove it from the landscape.

Summary

The Smith Property site clearly shows the correlation between the stoneline at the base of the Foothills colluvium and locally derived alluvium. The alluvium, stoneline, and the colluvium overlying the paleosol appear to be early Holocene in age. By implication, the paleosol is pre–Holocene, having formed during the Wisconsin and, perhaps, during the interglacial preceding it. There was very little mixing of materials at this site. For example, the paleosol contained very little gravel, though it is overlain by alluvium that is primarily gravel. Apparently, alluvial–colluvial episodes similar to the early Holocene event were uncommon during the interval in which the paleosol was actively forming.

Specific questions asked prior to sampling and analysis were answered as follows: (1) The characteristics of the paleosol are consistent with *in situ* formation from bedrock. For example, talc, a mineral resistant to soil weathering, was found in the paleosol and bedrock on the east side of a major shear but was undetected in the paleosol and bedrock on the west side only a few meters away. Today, the Holocene colluvium overlying both paleosols contains talc. Thus, had there been significant colluvial events during the development of the paleosol, talc would have been mixed into the paleosols on both sides of the fault. (2) This slickensided clay within the shear zone contains predominantly montmorillonite, a mineral formed as a result of near–surface weathering under poor drainage conditions. Tectonic slickensides within this clay apparently post–date the formation of montmorillonite. In the foothills, montmorillonite forms within tectonic shears more rapidly than the erosive forces can remove it from the landscape. (3) The clay gouge within the shear zone was formed *in situ* from talc–free bedrock. Significantly, it was not translocated from the talc–containing paleosol immediately above it. (4) The colluvium and alluvium were derived from the same bedrock types during the same erosive episode. Both had clay fractions containing kaolinite or chlorite—minerals derived from upland soils or bedrock not present in the immediate vicinity of the two profiles sampled.


WEST
EAST
TALC-FREE META-SEDIMENTARY BEDROCK
TALC-FREE BEDROCK PARTIALLY WEATHERED TO MONTMORILLONITE AND THEN SLICKENSIDED
MT
MT?
AREA SAMPLED (296/77)
S2 SHEAR
SI SHEAR (?)
TALC-CONTAINING META-SEDIMENTARY BEDROCK
200
250
Depth (cm)

igure 8. Expanded view of the relationships between the slickensided montmorillonitic clay and the bedrock geology surrounding sample 296/77. The ower surface of the slickensided shear may be talc–free, indicating movement since the formation of montmorillonite within the talc–free bedrock above an old fault contact.

Hubbard Road

The Hubbard Road site is unique in that there the Foothills colluvium overlies an oxidized paleosol (Photo 14; Swan and Hanson, 1977, p. A–31) that appears to have been reduced at one time. The site is within the DeWitt lineament 11 km northwest of the proposed Auburn dam (Table 2, Figure 1).

In trench 2, a westward–dipping shear zone separates a platy granitic dike on the east from massive to platy metasediments on the west (Figure 9; Schwartz and others, 1977, page A–50). Slickensides within the shear zone appear to extend through the paleosol (Photo 15) as do broken pieces of yellowish rock (Figure 9, Photo 14).

Because the paleosol appears to contain expansive clays, the slickensides or soil shears (Figure 9, Photo 15) may have resulted from or may have been influenced by downhill soil creep. The north wall of this trench, as well as both walls of a parallel trench 7 m to the south, also has slickensides extending from the fault plane through the paleosol. Slickensides and shrinkage cracks were observed in other parts of the paleosol that are not immediately above the shear zone. These, however, appear to extend in almost every conceivable direction. Their orientations were not indicative of downhill creep.

Sampling Program

The occurrence of the paleosol on both sides of the fault (Figure 9) allowed us to test the soil creep hypothesis. The south trench has a paleosol only on the west side of the fault. If fault movement occurred after the paleosol had formed, then the presence of the paleosol on both sides of the fault might indicate substantial soil creep. If this was the case, the paleosol would have formed from the massive metasedimentary rock on the west side of the fault. Paleosol samples from both the east (286/77) and west (287/77) sides of the fault might then contain residual minerals derived from the bedrock on the west (289/77). The paleosol on the east side of the fault would then be more closely related to the bedrock on the west than to the bedrock beneath it (288/77).

About 110 m north of the trench in Figure 9, there is a north–south trending drainage ditch that exposes a reduced paleosol. Like the oxidized paleosol of Figure 9, this is overlain by an oxidized colluvium. A sample (290/77) of this reduced paleosol was obtained for comparison to the oxidized paleosol. The plasticity, expansivity, and other field characteristics of both paleosols indicated that they must have originally formed under poorly drained conditions.

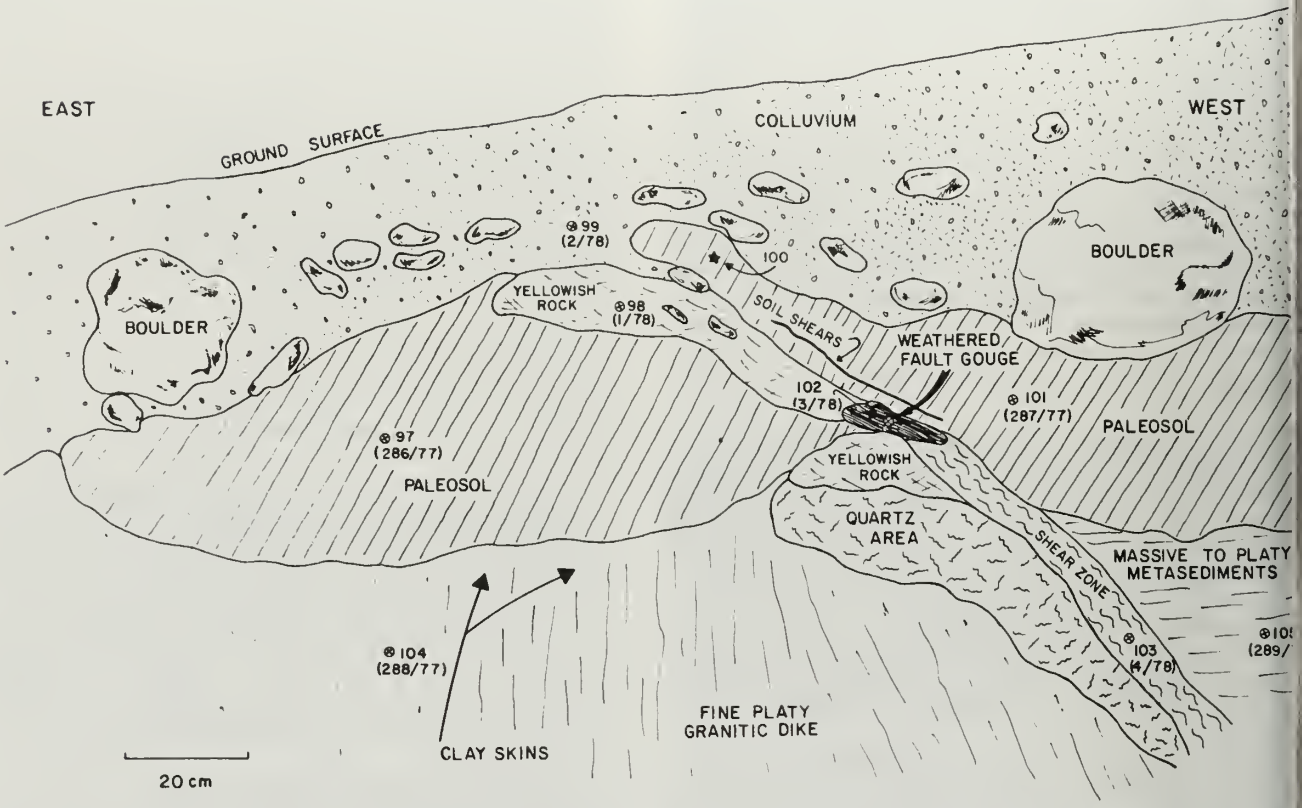


Figure 9. Log of the fault feature in the south wall of trench No. 2 at the Hubbard Road site. CDMG Lab. Nos. are in parentheses; the rest are 778 field numb

Photo 14. Fault feature in oxidized paleosol overlying a shear zone in the south wall of trench 2 at Hubbard Road. The colluvium contains a partially preserved stoneline within 20 cm of the ground surface at a point immediately above slickensides that appear to extend from the shear zone. Parallel strings are one meter apart.

to 15. Close–up of slickensides or soil shears extending through the eosol at Hubbard Road. Area photographed was between samples 100 and 77B102 (Photo 14 and Figure 9). Scale in cm and inches.

rticle size analysis

aleosol samples 286/77 and 287/77 from either side of the lt had nearly identical particle size distributions (Table 1). example, there was 61 percent clay, 10 percent medium silt, 11 percent fine silt in each. In addition, the pH was nearly same (4.52 and 4.36). Such low pH's indicate that the paleo- was well drained for a considerable length of time.

ikewise, the gleyed paleosol (290/77) about 110 m north of site had a particle size distribution reminiscent of the oxi- ed paleosol. About the only dissimilarity was that the reduced eosol had 6 percent less clay and about 6 percent more me- m and fine silt than the oxidized paleosol. The pH was 6.61, alue common for other reduced paleosols of the foothills ble 1). Presumably, this is what the paleosol above the shear e may have been like prior to obtaining its presently well– ined position in the landscape. This supposition may be fur- r enhanced or disproven by clay mineralogical analysis.

y mineralogy

ll samples of paleosol and bedrock from Hubbard Road tained smectite as a dominant mineral in the clay fraction ble 3). A kaolin mineral (halloysite or kaolinite) was found in all samples except the bedrock sample from the west side of the fault (CDMG no. 289/77). Instead, this sample had mica, a mineral not detected in the other samples. Vermiculite, an early weathering product of biotite in acidic soils (Douglas, 1977, p. 268), was detected in all samples except CDMG No. 290/77, which was from the reduced paleosol. It appears that the bedrock sample from the west side of the fault is less weathered than the other materials, for it still has significant amounts of mica and lacks kaolin in spite of its low pH of 4.86 (Tables 1 and 3).

As mentioned previously, the expansive character of the paleosol above the shear zone indicates that it has probably formed under poor drainage conditions. The dominance of smectite in the clay fraction supports this contention. However, the low pH and the reddish color of the oxidized paleosol are concordant with its present well–drained position in the landscape. Other paleosols in the foothills have pH's near neutrality (Table 1) and colors closer to the olive–green of most gleyed soils. These are overlain by colluvium that is usually well oxidized much like it is in the Hubbard Road area.

Mineralogy of silt and bedrock

X–ray patterns of finely ground bedrock were compared to the silt fractions (63–2 um) obtained from the paleosol on both sides of the fault (Figure 10). We expected the paleosol to contain minerals derived from the west side of the fault. This would be the direction of any downhill creep or slope movement. However downhill creep could not be substantiated by the data. Quartz, for example, was a dominant material in both the paleosol and the bedrock on the east side of the shear (Figure 10). Hornblende was a dominant mineral in the bedrock on the west side while quartz was absent. Significantly, hornblende was undetected in the silt fraction of the paleosol and in the bedrock on the east. The paleosol obviously did not form entirely from the bedrock on the west. The absence of significant hornblende in the silt fraction of the paleosol could be explained by intense weathering or by the concentration of hornblende in other size fractions (e.g., hornblende was found in a heavy liquid concentrate from the 246–124 um fraction [Swan and Hanson , 1977, p. B–44]).

The fact that the paleosol on the upslope side of the fault does not completely reflect the mineralogy of the bedrock beneath it, indicates that it is to some extent nonresidual. Even so, it is entirely lacking in large cobbles and large boulders characteristic of the type of colluvium now above it (Figure 9). If the paleosol formed partially from colluvium, it was very fine grained, or the colluvial event occurred very early in the development of the soil and any cobbles have long since disintegrated.

Yellowish bedrock is mixed into the paleosol on the east side of the slickensides that extended up from the shear zone (Figure 9, Photo 14). This type of bedrock–soil mixing appears to post–date paleosol formation—it may be a result of "tectoturbation."

Charcoal date

Charcoal was found at the base of the paleosol (70 cm depth) in the south wall of the north trench about 4 m east of the shear zone. This occurred in a horizontal layer between one and five centimeters thick and 60 cm long. A radiocarbon age of 1700 B.P. was obtained by the U.S. Geological Survey (USGS–221). Soil development within the paleosol would have required at least ten times as much time. Thus the charcoal must have been introduced after paleosol formation or it may have been contaminated by modern roots, a frequent occurrence at depths of less than a meter.

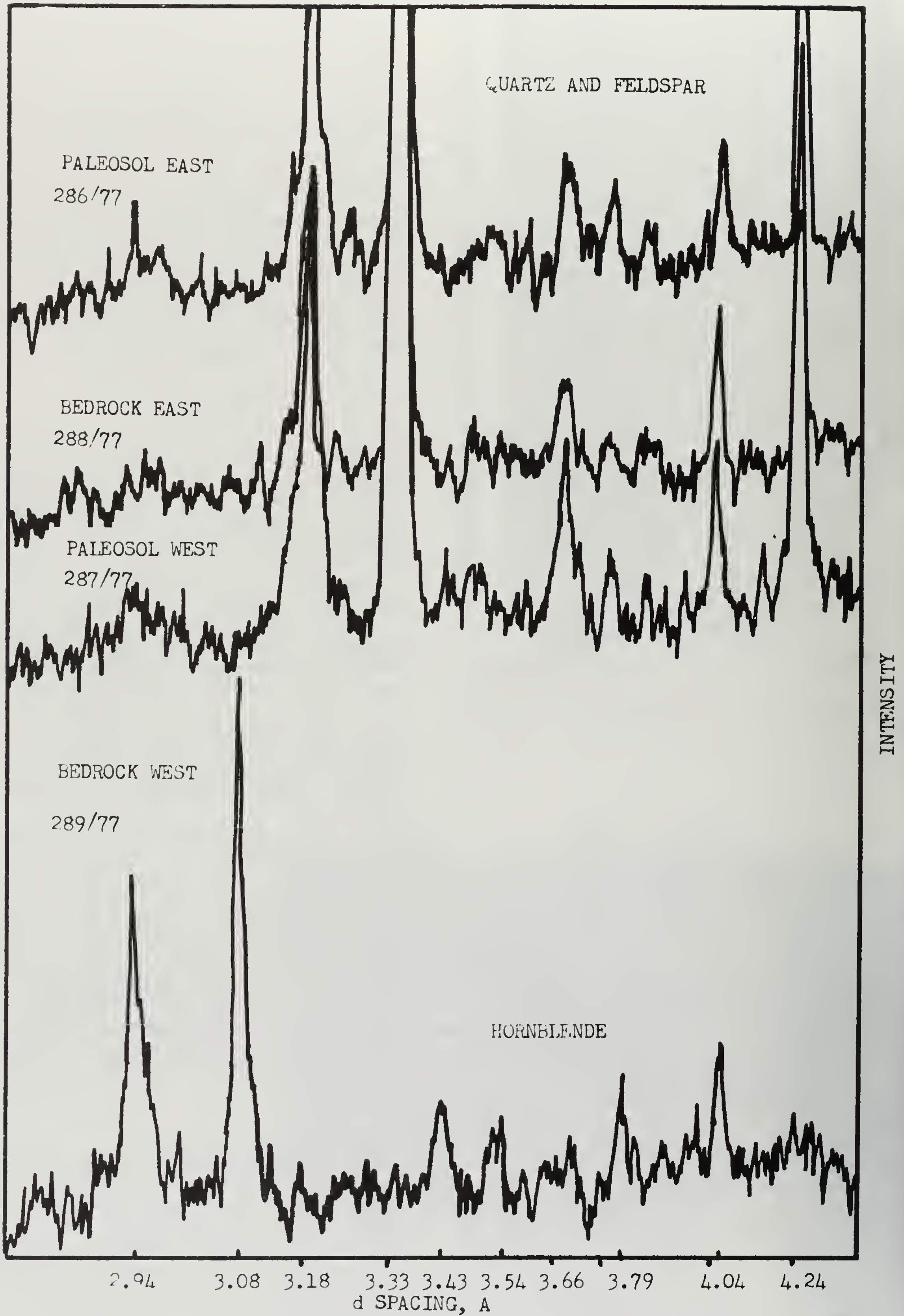


Figure 10. X-ray diffraction patterns of whole samples from either side of the shear zone at the Hubbard Road site. The paleosol on both the east and west sides of the fault contains quartz whereas the bedrock on the west does not.

mmary

At least three major changes have occurred in the landscape he Hubbard Road site. First, the drainage of a former humic y soil (today's paleosol) above the shear zone had to change m poor to good—perhaps through fault movement. Second, re must have been a period of landscape stability that was g enough to oxidize the iron and decrease the pH of the humic y. Third, a period of intense erosion must have removed most the soil from the east side of the fault and resulted in the osition of oxidized colluvium upon the already oxidized eosol.

Slickensides or soil shears in the paleosol appear immediately ve the shear zone. This evidence, along with the apparent roduction of relatively unweathered bedrock into the paleosol ng the same plane, suggests possible post–paleosol tectonic vement. The other alternative, soil creep, could not be conned because the mineralogy of the paleosol remnant on the vnslope side of the fault is consistent with formation *in situ* ile the one on the upslope side is not.

Railroad Tunnel

he Railroad Tunnel site lies along the approximate strike 70W) of fault F–0 about 2.0 km NW of the proposed Auburn n (Figure 1). F–0 appears to offset most if not all the faults t cut through the dam foundation (Frei and others, 1977, wing No. 7302). In addition, F–0 appears to be the fault ated nearest the low point in a recent leveling survey that was ducted along the Southern Pacific railroad tracks (Bennett, lor, and Toppazada, 1977, p. 52). The elevation dropped r 30mm(± 1mm) between 1947 and 1969. A more recent vey reveals a similar elevation decrease in the same area since 9 (Bennett, 1978).

he railroad tunnel (built in 1910) did not show any obvious lacement, but then the tunnel is coated and the bedrock is accessible. However, a fault occurs in the excavation at the north end of the tunnel. It is southwest dipping with considerable vein quartz much like the F–0 fault in the dam area. In fact, numerous excavations occur on the northwest side of the railroad cut. These appear to be gold prospects that are probably part of the old Ophir gold mining district discussed by Lindgren (1894). The F–0 fault apparently extends into and becomes a part of the fault system along which most of the gold was found in association with vein quartz.

We excavated the southwest side of the railroad cut where the fault was exposed near the natural surface. Here, a clayey, well developed paleosol occurs on the northeast side of the fault (Photo 16; Table 1, CDMG. No. 327/77). The material beneath it (CDMG No. 328/77) was mottled loam. No clear evidence could be found for an equally well developed paleosol on the other side of the fault (the hanging wall). Paleosol development also occurs in trench BHT–86 on F–0 as it approaches the dam site. That site also had a well developed paleosol on the footwall of one of the strands of F–0. It was laterally more extensive whereas the one at the railroad tunnel appears to be only a meter wide, a result of preferential weathering along the fault. Of course, without stratigraphic development that is continuous across all strands of a fault, it is nearly impossible to prove inactivity. We sampled the Railroad Tunnel site mainly to compare this paleosol with others in the foothills.

Particle size distribution

The paleosol (11B2b) had 52 percent clay while the parent material (11C11) had only 18 percent (Table 1)—a nearly three–fold increase. This clay might have developed *in situ*, for evidence of contamination by other materials is lacking. For example, there was no gravel in either the paleosol or the parent material. This was in spite of the fact that the 45–cm colluvial unit overlying the paleosol had considerable gravel and cobble.

The low pH (5.44) and the dark yellowish brown (10YR4/4) color of the 11B2b horizon usually indicates moderate to good drainage. The 11C11 horizon was similarly acid, though the mottling within it indicates that it is saturated part of the year.

Photo 16. Paleosol remnant overlying the northeast side of a possible extension of fault F–0 in a cut north of the Railroad Tunnel. The colluvium is about 45 cm deep. Both the colluvium and the paleosol are fairly well–drained.

Clay mineralogy

The clay mineralogy of the 11B2b horizon was dominated by montmorillonite and beidellite with moderate amounts of vermiculite and a trace of kaolin (Table 3). The 11C11 horizon also had abundant beidellite, moderate vermiculite, and a trace of kaolin. Except for the physical break down of silt and sand–size particles, mineral weathering in this paleosol seems to have transformed some of the beidelite to montmorillonite. This transformation was also noticed for paleosol development at the Smith Property although at that site the pH was slightly higher and drainage was poorer (Table 3).

Summary

The Railroad Tunnel site provides an excellent year–round exposure of a paleosol associated with the Foothills fault system. The paleosol is currently well drained, acidic, expansive, and residual. Significantly, it contains no gravel and gives no evidence of having been influenced by significant colluviation during its development. The contact with the overlying Foothills colluvium is abrupt and there is virtually no mixing of the coarse, cobbly colluvium with the clayey paleosol. The residual, cobble–free characteristics are similar to those considered typical of the Foothills paleosol at the other sites we have studied. The paleosol occurs on a possible N70W extension of fault F–0, which traverses the site of the proposed Auburn dam. Significantly, the paleosol occurs only on the footwall of a SW dipping shear, possibly because of erosion subsequent to tectonic movement. In this regard, the paleosol mirrors a similar occurrence in trench BHT–86 on the strike of fault F–0 nearer to the dam site.

Trenches ST–64 and BHT–1 at the Auburn Dam Site

Trenches ST–64 and BHT–1 are about 290 m south of the right abutment of the proposed Auburn dam (Figure 1; see also Frei and others, 1977, Drawing 7302). Trench ST–64 contains a large segment of an excellent laterally contiguous paleosol (Photo 3). This paleosol has an appearance very similar to the crescent–shaped paleosol in BHT–1 (Photo 4). The unusual crescent shape may have resulted from soil creep subsequent to soil formation near the head of an ancient gully, or a small basin–like environment may have existed here previously. The present surface topography is more nearly level over this locality (Photo 4). This is reminiscent of the old gully fill in ST–107 that also does not conform to the present topography (Borchardt, Taylor, and Rice, 1980).

Neither of these paleosols occur directly over specific fault fractures although they occur within 50 m of a 60 cm offset that occurs in the Maidu East fault zone (Borchardt, Taylor, and Rice, 1980). These paleosols are important because, like the other paleosols we have been discussing, they are stratigraphically located between the surficial colluvial unit and the Mesozoic bedrock. Physical and mineralogical data will help substantiate a correlation with these other paleosols that actually overlie shears elsewhere along the Foothills fault system. This would bring the correlation within geographical proximity of the dam foundation.

Sampling program

We sampled (CDMG No. 275/77) the crescent–shaped paleosol in BHT–1 at about 15 cm to the right of a marker that read: "17–44 bs, hm" (Photo 4). This was at a depth of 120–1 cm. The first 120 cm at the site was primarily Mehrten collu um. Weathered amphibolite occurred beneath the 145 cm dep

In trench ST–64, we took five samples, two of which we submitted for laboratory analysis. The first was from the pale sol (CDMG No. 274/77) at a depth between 83 and 97 cm (th is, at a depth equivalent to the horizon at the 35 to 40 inch dep in Photo 3). The second was of the amphibolite parent mater (CDMG No. 273/77) at 127–137 cm.

Particle size analysis

The paleosols at this locality were high in clay like most oth in the foothills (Table 1). The crescent–shaped paleosol of BH 1 (275/77) had 68 percent clay and 3 percent gravel while t paleosol in ST–64 (274/77) had 58 percent clay and 32 perce gravel. An examination of the gravel showed only amphiboli there was no contamination from the Mehrten colluvium abo

Clay mineralogy

The clay mineralogy of both paleosols was quite similar. W obtained a small amount of clay (< 2 um) from the sample amphibolite in ST–64. This had considerable vermiculite a small amounts of montmorillonite and kaolin (halloysite or ka linite).

The paleosols had more beidellite, more montmorillonite a kaolin and less vermiculite than the parent material (sampl 274/77 and 275/77 vs 273/77, Table 3). The transformation vermiculite to smectites such as montmorillonite and beidelli is a common occurrence (Borchardt, 1977a, p. 309). In a wel drained, acid environment, mica–derived vermiculites are rel tively unstable (Kittrick, 1973). However, a mica precursor w not detected in either the paleosol or the amphibolite. Mic derived vermiculite would have been completely destroyed if t paleosol had been under the present acidic conditions (pH Table 1) for great lengths of time. It is not known how mu time would be required to destroy all the vermiculite. In a case, it is very likely that the pH of this paleosol was higher a the drainage poorer during its formation. Such is the case for t humic gley soil presently forming in BHT–66 only 60 m to t northwest (Borchardt, Taylor, and Rice, 1980).

Summary

The paleosols in ST–64 and BHT–1 appear correlative wi each other and with the other moderately to strongly weather paleosols of the foothills. Like the paleosols elsewhere, the appear to have formed *in situ.* Also like the others, they represe a lengthy period of landscape stability free from colluvial co tamination. Their greenish colors and expansive characteristi reveal a soil–development history that includes either mo precipitation or less adequate drainage prior to their inundati by oxidized colluvium.

Trench ST–65 at the Auburn Dam Site

The paleosol in ST–65 (Photo 2) has been logged (Frei an others, 1977, Drawing No. 7354), measured, photographed, d scribed, and discussed in detail (Shlemon, 1977b, p. 14–2 Shlemon, 1978, p. 32–36). This is largely because it overlies pa of the Maidu East fault zone within 580 m of the right abutme of the proposed Auburn dam. Like other paleosols in the foo hills, this one lies beneath oxidized colluvium and above shea t offset Mesozoic crenulations in the bedrock. Unfortunately, Tertiary Mehrten Formation does not extend into this ıch, so we cannot be positive that the underlying shears repre- t the entirety of the Maidu East fault zone.

ncidently, the full extent of post–Tertiary shearing in the idu East fault zone can be seen in trench ST–68 about 240 m her south. Five meters of apparent vertical offset occurred ıg three large shears and numerous small ones (Frei and ers, 1977, Drawing No. 7352). The shear zone is over 60 m e at this point, but as it leaves the Mehrten Formation, lence for this much movement greatly diminishes. A strand he Maidu East fault zone continues through trench ST–65 on through trench ST–91. Here, 1.4 m of apparent vertical et occurs in a zone less than a cm wide (Photo 17). The rowness of this zone seems to preclude multiple events as ıg responsible for the offset. Repetitive movements within cm of each other would appear fortuitous for these materials. es between 30 and 50 degrees on the fault gouge in ST–91 cate that lateral movement is possibly greater than the verti-

he most obvious zone of Cenozoic shearing in ST–65 is about wide. The paleosol in question lies across this entire width oto 2), and we can therefore conclude that dramatic one– e events on the order of a meter or more of vertical offset have occurred since the paleosol began to develop. However, lat- movements or vertical offsets of less than 15 cm (from ıre 4 of Shlemon, 1977b) could not be ruled out without a more detailed investigation. We felt that such an investigation was not warranted in view of the ambiguities in the remainder of the trench. These include numerous "dull to highly polished slicks" and zones of talcose serpentine (Frei and others, 1977, Drawing No. 7354) that could indicate or conceal additional Cenozoic shearing. As elsewhere, these talc zones are zones of weakness along which the Maidu East fault zone seems to propagate both to the north and south (Frei and others, 1977, Drawing 7302). One of these, T–25, eventually transects the right abutment of the dam. A completely satisfactory paleosol cover is not available for these zones.

o 17. Offset with 1.4 m vertical component in a sandstone unit of the ary Mehrten Formation in trench ST–91 about 430 m from the right ment of the proposed Auburn dam. Maidu East fault zone.

The paleosol in ST–65 has apparently formed upslope of a water barrier formed by the serpentine body that transects the eastern end of the trench. There is a break in slope at this point, further testifying to the serpentine's relative resistance to erosion. Paleosols do not occur on the steep slope further down the side of the canyon. The colluvial soil here is reddish and well oxidized, much like the colluvial unit overlying the paleosol upslope from the water barrier (Photos 2 and 18). There are numerous small water barriers throughout trench ST–65, leading to considerable irregularity in paleosol development. For example, soil creep is evident in some sections where oversaturation results in downslope movement of the paleosol (Photo 18). Sometimes the movement overrides bedrock, destroying the B3 horizon (Photo 18), the transition zone containing "bedrock affinities" that normally indicate soil formation *in situ*. Most of this soil creep is precolluvium in age (Wisconsin) because the stoneline at the base of the shallow colluvial unit (about 75 cm thick) remains undisturbed. However, on the north wall of the trench, the paleosol has overridden the colluvium—obviously a Holocene phenomenon. Just a few meters away, the paleosol is more stable, presumably because of slightly better drainage conditions (Photo 2).

Even so, the olive brown and pale yellow colors (Shlemon 1977b, p. 23) of most paleosol remnants in ST–65 indicate reducing conditions and pH levels that are likely to be higher than for well–drained soils of the same age. Soil formation under poor drainage conditions is vastly different from that under good drainage (Borchardt, Taylor, and Rice, 1980). For example, the rate of mineral weathering is usually related to the degree of soil acidity. Consequently, mica content decreased with pH for Holocene soils in Wisconsin (Borchardt, Hole, and Jackson, 1968, p. 401). Neutral soils had twice as much mica as those with pH's below five. Thus, there are certain difficulties with correlating reduced paleosols with oxidized paleosols and with oxidized soils on the basis of development. Fortunately, the stratigraphic relations at ST–65 are consistent with those elsewhere in the Foothills fault system.

Sampling program

As mentioned, we did not attempt a detailed sampling of this trench. Instead, we sampled the 111B2bg, 111B3bg, and 111R horizons of the paleosol in order to establish the relative degree of weathering. Samples were taken at station 71 (Frei and others, 1977, Drawing 7354) along the south wall of the trench. Our sample 307/77 is approximately correlative with Shlemon's (1977b, p. 18) 111B21b, 111B22b and IVB2tb horizons. Sample 308/77 is representative of his IVB3b horizon. Sample 309/77 is representative of his RI (amphibolite) horizon.

Particle size distribution

There was about 50 percent clay in the 111B2bg horizon and 30 percent in the 111B3bg horizon (Table 1, CDMG Nos. 307/

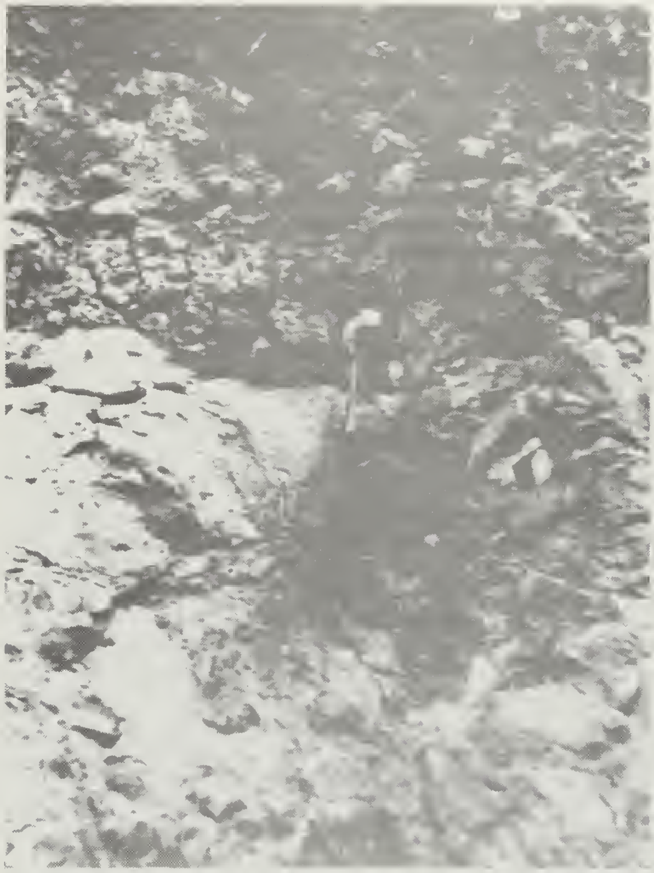


Photo 18. Reduced paleosol east of the one overlying the Moidu East fault zone in Photo 2. The paleosol/bedrock contact is very obrupt, indicating that considerable soil creep occurred prior to the deposition of the oxidized Mehrten colluvium overlying the paleosol.

77 and 308/77). This, along with a corresponding decrease in silt content, indicates the usual direction of physical breakdown that occurs in residual soils. The gravel analysis, however, indicates some surficial contamination of the paleosol. There was no gravel in the 111B3bg horizon but 1.4 percent appeared in the 111B2bg horizon above it. Likewise, there was more than 4 times as much coarse sand (2–1 mm) in the surface of the paleosol than at the bottom. A small amount of colluvial contamination might be indicated as per Shlemon's field observation (1977b, p. 17). He reports two buried B2 horizons based upon their being separated by "a weak stone line of andesitic pebbles (Mehrten Formation)." This observation was made at station 25, 14 m west of our sampling site.

However, close examination of the gravel from sample 307/77 revealed no andesitic pebbles that would substantiate colluviation from the Mehrten Formation. As we saw before, the paleosol in ST–64 also did not contain andesitic pebbles from the overlying colluvium. Most of the gravel–size particles in 307/77 were small irregular quartz pebbles. Others were also derived from Mesozoic rocks found within a few meters of the site. Although this gravel indicates a small amount of locally derived colluvium in the 111B2bg horizon, we believe it is insufficient evidence to conclude, as Shlemon does (1977b, p. 17), that two significant stages of paleosol development occur in trench ST–65.

The weak stoneline, however, does clearly indicate that the paleosols in the foothills were subject (like the soils) to small
amounts of surficial contamination. It is not surprising, th
that the upper parts of these paleosols would have extrane
materials whose placement is dependent upon various proce
involving pedoturbation. However, local colluviation and
creep are phenomena that should not be correlated with the t
of colluvial episode we see exhibited in the upper 50–75 cm
this section (Photos 2 and 18). Particle size analyses of a sim
colluvial unit at trench ST–68 to the south showed that the fi
(less than 2 mm fraction) in the stoneline and those in
material above it are nearly identical (Borchardt, Taylor,
Rice, 1980). The entire colluvial unit at ST–65 has been de
nated as "Qc1" by Frei and others (1977, Drawing No. 73
although Shlemon (1977b, p. 18) considers the A horizon t
Q_{c1} and the stoneline to be Q_{c2}. We consider the stoneline
the material above it as primarily the result of a single perio
landscape instability. Likewise, the paleosol appears to repres
only one significant stage of landscape stability.

Clay mineralogy

Layer silicates in the bedrock at station 71 are very comp
The clay fraction isolated from the bedrock had chlorite,
miculite, mica, montmorillonite, and beidellite according to
ray diffraction (CDMG No. 309/77, Table 3). The chlorite
mica components indicate that the rock is more like a chlo
schist than an amphibolite.

The chlorite–vermiculite component gives an excellent 1
peak that collapses to 12A upon K–saturation and heating
550°C. This indicates that the mineral is an intergrade
interleaving of layers of vermiculite and chlorite. Most likely,
other minerals, mica and montmorillonite, are part of this c
plex (Borchardt, Jackson, and Hole, 1966). As such layer
cate complexes weather, mica and chlorite components ten
transform, first to vermiculite and beidellite, and then to m
morillonite. This progression is evident in the data for
111B2bg and 111B3bg horizons. Because montmorillonite is
end product of this reaction, it is not unusual to find it con
trated in the finest clay fraction and eligible for translocatio
deeper horizons.

As seen also for paleosols elsewhere in the foothills, mica
not detected in the B horizon, and thus the first part of
following reaction appears more or less complete:

$$\text{mica} \rightarrow \text{vermiculite} \rightarrow \text{montmorillonite.}$$

The second part of the reaction is only partially complete,
thus this paleosol is "moderately" weathered, again, much
the others we have seen in the foothills. Intensely weathered s
normally do not have mica, vermiculite, or mafic chlorite,
then, such soils usually are well–oxidized, acidic, well–leach
and reddish in color.

Summary

The paleosol in trench ST–65 is moderately weathered
occurs in the same stratigraphic position as others overlying
Foothills fault system. Like the others, it is found near a w
barrier—one produced by a geologic contact that also is assoc
ed with Cenozoic faulting. The well–oxidized colluvium ove
ing the reduced paleosol contains a stoneline that forms
abrupt contact with the paleosol. Colluvial contributions to
paleosol appear minimal and, for the most part, the two
unmixed. Throughout trench ST–65 the colluvium remains
dized—perhaps indicating that the high–moisture conditi
that produced the paleosol have not yet returned.

The Knolls

he Knolls site is located 15.3 km south of the proposed urn dam (Figure 1). The nearby Luneman Road site, also hin the Rescue lineament zone, is a textbook example of the gular growth of vegetation (Photo 8) and seepage in water riers associated with faults and geologic contacts (Photo 5). area has many hummocks produced by cattle movement ugh wet expansive soils (Photo 19). Obviously, such pedoation results in extremely variable A horizon thicknesses oto 20) that complicate the evaluation of the most recent ting. Elsewhere, almost horizontal slickensides indicate lat- movement of these soils by massive down–hill creep or or landsliding. We therefore concentrated our efforts on a rby trench to the south which was better drained than the r trenches, being in a small drainage divide called "The lls" by Schwartz and others (1977, p. A–51 to A–58).

he Knolls trench has several eastward dipping shears that the initial appearance of transecting the paleosol (Schwartz others, 1977, p. A–58; Figures 11 and 12, Photo 21). About o 60 cm of oxidized colluvium overlies the paleosol in this ch. The larger materials tend to form a faint stoneline at the om of the colluvium. The laterally extensive sequence of osol–bedrock–paleosol is repeated throughout the trench rever well–defined shears can be detected in the talcose bed-. The paleosol appears to have been almost entirely eroded y during the colluvial episode. Only discontinuous "soil ues" remain where they have formed in preferred drainage s produced by shearing.

pling program

or particle size and clay mineralogical analyses, we sampled hanging wall above a shear next to a marker that read: 170 bs, hm, Paleo B_2" (Figure 11, Photo 21; Schwartz and rs, 1977, p. A–58, station 76). (Note: Sampling sections or ls at stations 64 and 76 on p. A–58 apparently have been interposed.) A sample of the 111B2b and 111R1 beneath was obtained.

In viewing the features in Photo 21, we developed the hypothesis that the paleosol at this particular shear was offset approximately 10 cm down to the west. Thus the contact of bedrock with colluvium immediately above the shear might have resulted from vertical and lateral movement after formation of the paleosol. The bedrock on either side of the shear looked very similar, and so there was a chance that depth functions (changes with depth) of the paleosol on either side might be similar as well. We therefore removed representative columns of soil from either side of the fault (Figure 11). Each of these was broken into four parts comprising samples 278/77 to 281/77 on the east and 282/77 to 285/77 on the west.

Almost any characteristic can be used to prepare a depth function. We chose Ca/Fe ratios because only 1–gram samples of material are required and these can be analyzed rapidly by x–ray spectroscopy (XRS). Another advantage of XRS is that the samples can be retained permanently. They can be used for subsequent confirmation of results by using other elements in addition to calcium and iron. Ca and Fe are especially good indicators of soil weathering (Borchardt and Theisen, 1971). Ca is relatively easily leached from soils whereas Fe may precipitate as iron hydroxy oxide. Therefore, decreases in Ca/Fe ratios often indicate soil or rock weathering. Identical depth functions on either side of a fault could indicate areas that had undergone equivalent amounts of weathering of similar parent materials. Matching profiles at different depths might then indicate an offset paleosol.

Particle size distribution

This paleosol (CDMG No. 320/77) had 40 percent clay, an amount greater than at Spenceville, similar to Smith Property, and one–third less than at Hubbard Road (Table 1). The pH of the 111B2b horizon was 5.5 and the pH of the 111R1 horizon was 5.8, values to be expected for this moderate to well–drained paleosol.

Photo 19. Hummocks formed by the movement of cattle through springs and seeps in which expansive clays form along the Foothills fault system. Knife handle is 10 cm long. View north of Luneman Road site.

Photo 20. Variable A–horizon thickness in h
mock area of trench at Luneman Road. The br
ish or iron stains mark the temporary locatio
the water table at the base of the A–horizo

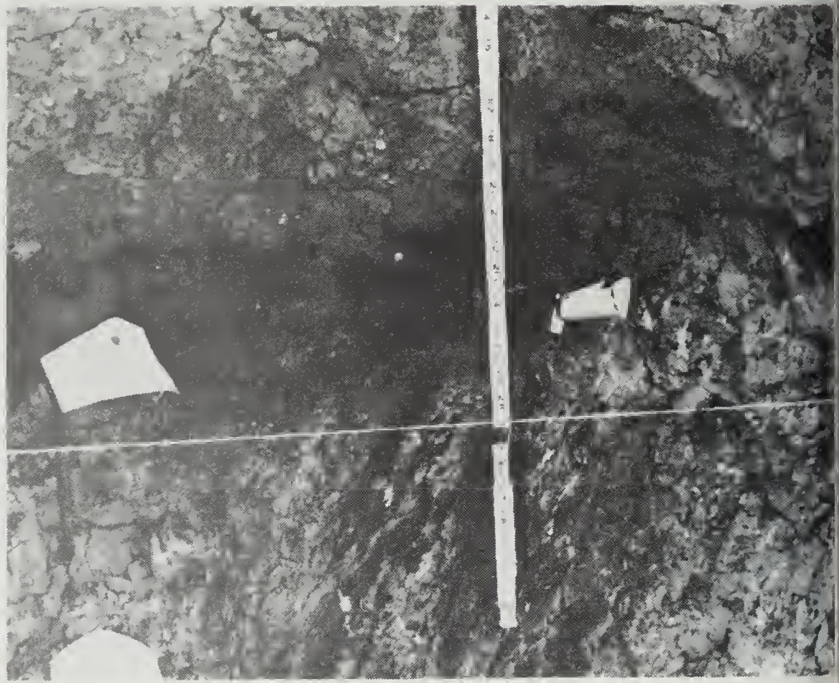
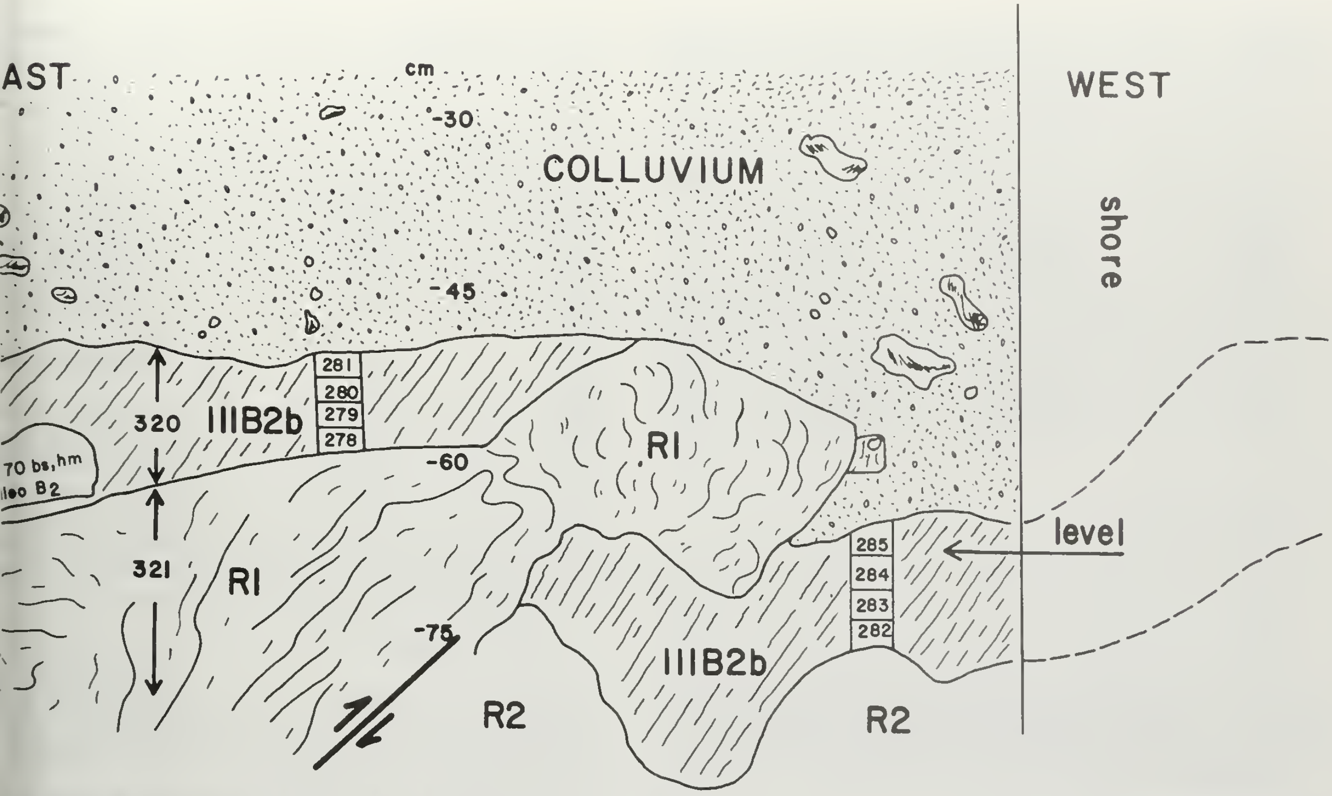


Photo 21. Fault features involving the paleosol above the main shear at The Knolls site.



11. Log of features and location of samples from area of Photo 21 at The Knolls site.

mineralogy

many respects, the clay mineralogy of this site was much
hat for profile no. 2 on the east side of the fault at the Smith
erty (CDMG No. 299/77, Table 3). Clay isolated from
rocks also contains talc, beidellite, and vermiculite. An
y analysis of a whole sample of the bedrock showed the
nce of an amphibole (tremolite) in addition to talc and a
mineral (presumably some combination of vermiculite and
llite). At both sites, the 111B2b horizon still contains ver-
lite, beidellite and talc. However, at Smith Property the
llite was transformed to montmorillonite under poor drain-
nd nearly neutral conditions (pH 6.7, CMDG No. 297/77,
es 1 and 3). At The Knolls, however beidellite was not
formed to montmorillonite (320/77, Table 3). Instead, it
have been slightly interlayered to form pedogenic chlorite.
dogenic chlorite often forms in the upper horizons of soils
aining expansible layer silicates under acidic conditions
chardt, 1977a, p. 312). These phases tend to be dioctahedral
relatively stable at low pH, whereas the mafic chlorite in the
athered rock is trioctahedral and unstable at low pH and
r oxidizing conditions. In any case, the evidence for pedo-
chlorite is rather subtle, being a rather small x-ray peak
out 12A after heating the sample at 550C. The 12A peak
ably results from an alternation of the 14A layers containing
oxy A1 and the collapsed 10A layers of K-saturated ver-
lite and beidellite.

nder the intense weathering conditions produced by good
age, the expansive clay minerals, smectite and vermiculite,
me completely interlayered to a 14A pedogenic chlorite.
pedogenic chlorite and kaolinite are common minerals in
ery old, intensely weathered soils of the southeastern part
of the United States. Pedogenic chlorite formation is pronounced in soils formed under 100 cm of rainfall in Oregon (Singleton and Harward, 1971). However, it appears to be rare in the Coast Ranges of California (Borchardt, 1977b). Under ideal conditions, the reaction rate is quite rapid. In Wisconsin, for example, pedogenic chlorite is common in Holocene soils (Fanning and Jackson, 1965). Further research on the conditions and reaction rates for pedogenic chlorite formation will aid in dating soil horizons.

Ca/Fe ratios

Ca/Fe ratios for the paleosol on the east side of the shear (Figure 11, Photo 21) were between 0.102 and 0.151 (Table 4). In contrast, Ca/Fe ratios on the west side were between 0.64 and 0.86. Therefore, we were unable to show offset by matching weathering profiles on either side of the fault.

There are several possible reasons for this result. First, the bedrock on either side of the fault is probably not as chemically similar as it appears upon visual examination. Significantly, the lowermost sample on the east had 37 percent more Ca and 22 percent less Fe than the lowermost sample on the west (Table 4). This reflects differences in parent material, for according to Schwartz and others (1977, p. A–58), station 78 is a relatively vertical dividing line between "metavolcanic rock?" on the east and metasedimentary rock on the west.

Secondly, lateral movement of soil across the fault must have been minimal. Normally, soils have rather uniform depths of weathering and also uniform depths of pedoturbation. Boundaries between different soil types are usually very gradual even though the soils have formed on different parent materials. The distinctness of such a boundary would tend to diminish with

Table 4. Ca and Fe contents and Ca/Fe ratios for vertical sections of the 111B2b horizon on either side of a fault at The Kr site.

CDMG No.	Depth, cm	Field No.	Ca %	Fe %	Ca/Fe
EAST OF FAULT					
281/77	55.0–57.5	77B138	1.05	10.2	0.102
280/77	57.5–60.0	77B137	1.04	10.0	.104
279/77	60.0–62.5	77B136	1.34	9.7	.138
278/77	62.5–65.0	77B135	1.33	8.8	.151
WEST OF FAULT					
285/77	65.0–67.5	77B142	0.72	11.2	0.064
284/77	67.5–70.0	77B141	0.83	11.4	.073
283/77	70.0–72.5	77B140	0.85	11.4	.074
282/77	72.5–75.0	77B139	0.97	11.3	.086
USGS Std AGV–1			3.50*	4.73*	

* From Flanagan (1973). Ca and Fe count rates in undiluted less than 420 um soil were compared directly with the andesite standard which was diluted 1:1 with i cellulose.

nearness to the soil surface. Like other soil properties, this variation will be dependent upon the five factors of soil formation—CTPOT, i.e., climate, topography, parent material, organisms, and time (Jenny, 1941).

Similarity anaylsis

How much variation should we expect for these paleosol horizons over this lateral distance of 50 cm? For that question we need a method of comparing the analyses for the samples on the east side of the fault with those on the west. One method is to use a similarity coefficient such as the SIMAN coefficient (Borchardt, 1972, 1974; Borchardt, Aruscavage, and Millard, 1972). The SIMAN coefficient gives a value between 1 and 0 that shows the relative degree of similarity between the data for any two samples having any number of variables. Similarity analysis was performed on the percentage of Ca, the percentage of Fe, and the Ca/Fe ratios of Table 4. Comparisons were made between corresponding samples from the vertical sections of paleosol taken from either side of the fault (Table 5).

If this paleosol had been laterally extensive across the geologic contact, we would expect the following trends. First, if the upper horizons of the two paleosol sections had been preserved, we would expect them to be very similar. This is because they would have been only 50 cm apart and, being A horizons, they would be subject to considerable lateral mixing or "pedoturbation." Then, as we proceed deeper and deeper into the soil, the influence of the two different parent materials would become more and more pronounced. Samples from similar depths in the two profiles would be more and more dissimilar as we approached the unweathered rock on either side of the fault.

The SIMAN coefficients (Table 5) show this trend but it is not pronounced. The coefficient for the bottom two samples (CDMG No. 278/77 and 282/77) of the vertical sections was $d_{(278,282)} = 0.67$. For the upper two samples (CDMG No. 281/77 and 285/77) it was $d_{(281,285)} = 0.74$, only slightly higher. For replicate analyses of 5 percent precision, we expect SIMAN coefficients of about 0.95. As an example, the closest thing to replicates we have in this experiment were two adjacent samples of nearly identical analyses (Table 4). These gave a SIMAN coefficient of $d_{(278,279)} = 0.94$. Thus, if the A horizons of these paleosols had been preserved, and if lateral pedoturbation thorough, we would expect the SIMAN coefficient for the upper soil samples to be greater than 0.94. Instead, the value these was $d_{(281,285)} = 0.74$ (Table 5).

In conclusion, we see that, as expected for most paleosols, A–horizon has been eroded away prior to burial. Also, at l one of the 111B2b horizons that remain at this site has b primarily formed *in situ*. If both 111B2b horizons had form from colluvium, for example, the similarities between samp from either side of the fault would have been much greater th they were. There is a good possibility that residual weather may have progressed more deeply into the bedrock on the w side of the shear than on the east (Photo 21). In this case, would not expect to match horizons on either side of the fa

Table 5. SIMAN coefficients for comparisons between Ca, and Ca/Fe analyses of soil samples from either side of a fc at The Knolls site.

EAST A	WEST B	SIMAN coeffici $d_{(A,B)}$*
281	285	0.74
280	284	0.79
279	283	0.69
278	282	0.67

$$*d(A,B) = \frac{\sum_{i=1}^{n} R_i}{n}$$

Where:

$R_i = X_{iA}/X_{iB}$ if $X_{iA} < X_{iB}$

$R_i = X_{iB}/X_{iA}$ if $X_{iA} > X_{iB}$

$X_{iA} =$ value of sample A for variable i

$X_{iB} =$ value of sample B for variable i

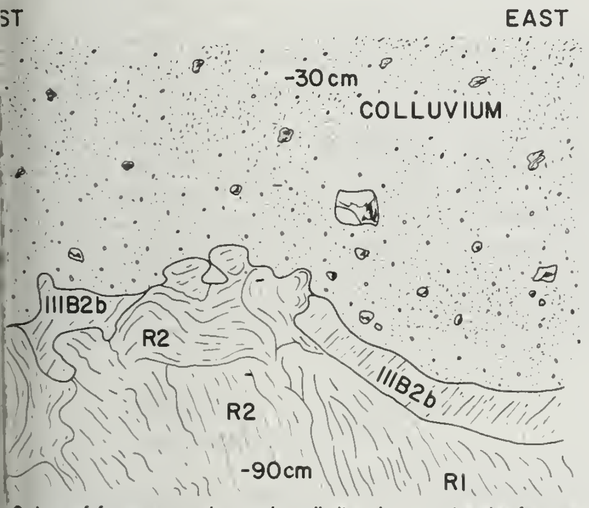
$n =$ number of variables

ould even consider designating such a more deeply weath- zone on the west as a 111B23b while designating the zone e east as a 111B22b.

ther support for this view was obtained on a recent visit s trench. After relocating the trench shore that obscured estern part of the paleosol, we could see that the paleosol ed about 10 cm in elevation as it continued west from the (Figure 11). Thus, the initial appearance of an offset in the sol may be a result of erosion of the 111B22b horizon from tra-thick soil. The extra thickness may have formed as a of preferential drainage within the shear (Borchardt, Tay- nd Rice, 1980).

ck–colluvium contacts

ere are numerous bedrock–colluvium contacts in the trench e Knolls. Such a contact occurred in the feature that we d in detail (Figure 11, Photo 21). It also occurred on the ite trench wall (Figure 12). It is likely that these contacts from severe erosion of a paleosol with an extremely irregu- il–bedrock boundary. Likewise, they may be the lower ants of small outcrops of bedrock that never had paleosols oped on them. Fault activity could be indicated because nsides are often associated with these contacts. Without a uous paleosol overlying the shears, it is difficult to rule out ic movement.



2. Log of features on the north wall directly opposite the features ge 11 and Photo 21 at The Knolls site.

hout exception, the bedrock–colluvium contacts observed he Foothills fault system (Figures 7, 9, 11, and 12; Photo icate very little if any transitional weathering between the his is in spite of the fact that these contacts are invariably less than a meter from the surface—the zone of active soil ion. This fact, along with the general observation that ithin the colluvium are only weakly developed, supports ocene age for the colluvial episode. Furthermore, there are nnants of colluvially–derived B horizons overlying the ol or the bedrock that would indicate anything on the f 75,000 years of soil development. This would be the t of time available for soil development if the colluvial ion was a result of the onset of Wisconsin glaciation.

ry

sol remnants at The Knolls occur primarily as soil formed within bedrock shears. The paleosol is acidic, generally well–drained, and moderately well–developed. Beidellite and vermiculite remain as the predominant expansive clays in lieu of montmorillonite which was formed at other sites from similar rocks under conditions of poorer drainage. Depth functions for Ca/Fe ratios of paleosol fragments on either side of a prominent shear failed to confirm an "apparent" offset. Instead, the data supported *in situ* soil formation within two slightly different bedrock types. Extensive erosion at the site has removed all but a few remnants of the paleosol. These remnants consist of "soil tongues" that formed as a result of preferential drainage within the numerous shears that occur throughout the trench. Intervening bedrock–colluvium contacts are extremely abrupt with little, if any, transitional weathering between the two materials. This observation, along with many others concerning the weak soil development in the colluvium, supports an early Holocene age for the colluvium and a Wisconsin age for the paleosol.

SUMMARY AND CONCLUSIONS

The age of the Foothills paleosol is very important for assessing the recency of faulting in the Sierra Nevada foothills. The paleosol was previously thought to have formed prior to 100,000 B.P., and thus, any disturbances within it would record movement since that time. However, during this study an alternative hypothesis was developed: *the paleosol overlying parts of the Foothills fault system was an active soil between 9,000 and 130,000 B.P.* Data from the literature and from our observations are not conclusive, but the following ten points strongly support this hypothesis:

(1) The overlying "Foothills colluvium" has been carbon dated at 9,130 ± 170 B.P.

(2) This carbon date coincides with the early Holocene pluvial period which occurred between 8,000 and 10,000 B.P. causing: (a) refilling of Pleistocene lakes Lahonton, Bonneville and Tulare, (b) extensive flooding and alluvial deposition in Humboldt County, California in 9,500 B.P., (c) growth of woodland vegetation in Southwestern deserts, (d) extensive hillslope stripping in the Southwestern deserts, the Mediterranean, and similar regions.

(3) The early Holocene pluvial period apparently was unique in that, since the end of the Illinoian (130,000 B.P.), there has not been an equally rapid change in climate from cool/wet to warm/dry followed by a pluvial period of such intensity and short duration.

(4) Within the Sierra foothills region the Wisconsin glacial period was one of relative slope stability in comparison to the early Holocene pluvial period. At each locality we examined, soil development within the Foothills colluvium was judged to be about one–tenth that within the Foothills paleosol. Thus, the colluvium has been exposed to soil development since 9,000 B.P., whereas the paleosol was exposed between 9,000 and 130,000 B.P. On the other hand, relative soil development would have been approximately equal in both colluvium and paleosol if the colluvium was a result of the onset of the Wisconsin glaciation.

(5) Relative soil development within the Foothills colluvium is intermediate between that in Holocene soils of a more humid climate (Wisconsin) and of a more arid climate (New Mexico). Clay skins were found in the colluvium and on an artifact of probable early Holocene age.

(6) Previous attempts at correlating soils of the Foothills colluvium with pre–Holocene soils of the Sierras and of the Great Valley failed to emphasize all–important differences

in parent materials. For example, inherited clay contents within the Foothills colluvium are relatively high, while those in glacial till and Pleistocene alluvium are low.

(7) Weak soil development in the Sierras and the Great Valley also results fom the fact that surfaces in these regions were available for perhaps half as much time and had half as much effective moisture as those in the foothills.

(8) Traces of cool–weather pollen (spruce, hemlock, etc.) preserved within certain ideally situated paleosols indicate their likely development during the last glacial period.

(9) The Foothills colluvium appears youthful because it mantles the present topography and there is relatively little mixing between the colluvium and the paleosol as indicated by (a) the generally cobble–free nature of the paleosol in spite of the coarse colluvium above it and (b) the still–oxidized state of the colluvium overlying reduced paleosols.

(10) The Foothills paleosol appears to have formed when the water table was higher, a more likely condition for the Wisconsin than for any interglacial period.

The data were complicated by the fact that water barriers along faults and geological contacts produce irregular drainage and soil development patterns.

With these considerations in mind, we evaluated fault features within paleosols overlying the Foothills fault system north and south of the proposed Auburn dam. The following conclusions were reached concerning the seven sites studied:

Spenceville

Slickensides on either side of a soil tongue indicate possible Holocene soil movement at the Spenceville site. This movement appears to be a result of tectonism because the slickensides are coincident with tectonic shears at depth. Other phenomena involving expansion and contraction cannot be ruled out entirely because the clay fraction from the fault gouge beneath the soil tongue contains montmorillonite, an expansive clay which may produce slickensides through seasonal changes in moisture.

An apparent offset in a comparable soil tongue in the northernmost trench may be a result of irregular soil development during the Holocene rather than tectonism. Ca/Fe ratios confirmed the visual observations of increased iron oxidation resulting from a possible decline in precipitation since the original development of the soil tongue.

Smith Property

The Smith Property site clearly shows the correlation between the tectonically undisturbed early Holocene stoneline at the base of the Foothills colluvium and locally derived alluvium. The paleosol contained very little gravel, although it was overlain by alluvium that was primarily gravel. Apparently, alluvial–colluvial episodes similar to the early Holocene event were uncommon during the interval in which the paleosol was actively forming. The clay mineralogy of paleosols developed in bedrock occurring on either side of the major shear at the site was consistent with their development *in situ*. For example, talc, a mineral resistant to soil weathering, was found in the paleosol and bedrock on the east side of the shear but was undetected in the paleosol and bedrock on the west side. Clay within the fault gouge contains predominantly montmorillonite, a mineral formed as a result of near–surface weathering under poor drainage conditions. Slickensides within this clay apparently post–date the formatio
montmorillonite.

Hubbard Road

At least three major changes have occurred in the landsc
at the Hubbard Road site. First, the drainage of a former hu
gley soil above the shear zone had to change from poo
good—perhaps through fault movement. Second, there m
have been a period of landscape stability long enough (at l
several centuries) to oxidize the iron and decrease the pH of
humic gley. Third, a period of intense erosion must h
removed most of the soil from the east side of the fault
resulted in the deposition of oxidized colluvium upon the alre
oxidized paleosol. Post–paleosol (Holocene) tectonic movem
is suggested by (1) slickensides or soil shears in the pale
immediately above the shear zone and (2) the apparent in
duction of relatively unweathered bedrock into the pale
along the same plane. The other alternative, soil creep, could
be confirmed because the mineralogy of the paleosol remnan
the downslope side of the fault is consistent with formatio
situ.

Railroad Tunnel

The Railroad Tunnel site provides an excellent year–ro
exposure of a paleosol associated with the Foothills fault syst
At this site, the Foothills paleosol is currently well drai
acidic, expansive, and residual. Significantly, it contains no g
el and gives no evidence of having been influenced by signific
colluviation during its development. The contact with the o
lying Foothills colluvium is abrupt and there is virtually
mixing of the coarse, cobbly colluvium with the clayey paleo
The paleosol occurs on a possible N70W extension of fault F
which traverses the site of the proposed Auburn dam. The pa
sol occurs only on the footwall of a SW dipping shear, possi
because of erosion subsequent to pre–Holocene tectonic mo
ment. There was no evidence for Holocene tectonism at this s

Trenches ST–64 and BHT–1
at the Auburn Dam Site

The paleosols in ST–64 and BHT–1 appear correlative
each other and with the other moderately to strongly weath
paleosols of the foothills. Like the paleosols elsewhere, t
appear to have formed *in situ*. Also like the others, they repre
a lengthy period of landscape stability free from colluvial
tamination. Their greenish colors and expansive characteris
reveal a soil–development history that includes either m
precipitation or less adequate drainage prior to their inunda
by oxidized colluvium.

Trench ST–65 at the Auburn Dam Site

The paleosol in trench ST–65 is moderately weathered
occurs in the same stratigraphic position as others overlying
Foothills fault system. Like the others, it is found near a wa
barrier—one produced by a geologic contact that also is assoc
ed with Cenozoic faulting. The well–oxidized colluvium ove
ing the reduced paleosol contains a stoneline that forms
abrupt and tectonically undisturbed contact with the paleo
Colluvial contributions to the paleosol appear minimal and,
the most part, the two are unmixed. Throughout trench ST

colluvium remains oxidized—indicating that the high mois-
conditions that produced the paleosol have not yet returned.

The Knolls

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gues formed within bedrock shears. The paleosol is acidic,
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rock types. Extensive erosion at the site has removed all but
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gues that formed as a result of preferential drainage within
numerous shears that occur throughout the trench. Interven-
bedrock–colluvium contacts are extremely abrupt with little,
ny, transitional weathering between the two materials. This
ervation, along with many others concerning the weak soil
development in the colluvium, supports an early Holocene age for the colluvium and a Wisconsin age for the paleosol.

Summary of Site Interpretations

Of the six sites overlying the Foothills fault system and studied in this report, two (Spenceville and Hubbard Road) showed evidence for possible Holocene fault movement. Two other sites (Smith Property and Railroad Tunnel) had features that could be interpreted as involving post–Illinoian (130,000 B.P.) fault movement. On the other hand, the paleosol overlying part of the Maidu East fault zone in Trench ST–65 near the proposed Auburn dam shows no tectoturbation since the beginning of the Wisconsin and perhaps since the end of the Illinoian. South of the proposed dam, data for the Knolls site was equivocal, with the nearby Luneman Road site offering evidence for Holocene soil movement involving slumping or creep associated with possible tectonically generated slickensides. In sum, the Foothills fault system should be considered tectonically active with minor Holocene movement in addition to considerably more extensive movement during the period 9,000–130,000 B.P.

GLOSSARY

CTPOT
Easily remembered acronym for climate, topography, parent material, organisms, and time; the five factors of soil formation.

FOOTHILLS COLLUVIUM
The surficial soil and transported rock unit that mantles the "Foothills paleosol" or the undisturbed bedrock within the western Sierra Nevada foothills (Tentative age: Holocene).

FOOTHILLS PALEOSOL
The residually–developed paleosol overlain by the Foothills colluvium within the western Sierra Nevada foothills.

PSEUDOPALEOSOL
Pedogenically – derived feature often mistaken for a paleosol remnant.

TECTOTURBATION
Soil disturbance resulting from tectonic movement.

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APPENDIX: METHODS

Particle Size Distribution

The particle size distribution was determined with the hydrometer method (Day, 1965), using sodium metasilicate instead of calgon. Carbonates were removed by treatment with pH 5 sodium acetate. This was followed by a mild hydrogen peroxide treatment as an additional aid to dispersion. An Iowa jet dispersion apparatus was used to further disperse the samples (Chu and Davidson, 1953). The temperature of suspensions was controlled at 25C with the use of a water bath and inexpensive temperature controller (Blue M Electric Company, Blue Island, Illinois).

X–ray Diffraction of Clay Fractions

Clay fractions (< 2 um) were obtained from the samples dispersed with sodium metasilicate. Approximately 0.7 g of sodium metasilicate was added to each 50 g of soil sample during the particle size analysis. This small amount of sodium metasilicate or its reaction products produced no detectable interference with x–ray diffraction analysis. Calgon (Na_3PO_4) was avoided as a dispersant because it reacts with the clay fraction to a greater degree than sodium metasilicate.

Magnesium saturated clay (< 2 um) samples were used to prepare slides by the smear–on–paste technique (Theisen and Harward, 1962). A 15 cm flexible plastic rule was used instead of a spatula for spreading the paste (Borchardt, 1977b). Slides were air dried one hour, placed in a 54 percent humidity chamber overnight, and x–rayed in a controlled 54 percent relative humidity environment. The presence of mica was shown by the presence of a 10A peak. Next, the sample was heated at 110C for two hours in glycerol vapor (Brown and Farrow, 1956) which was then allowed to condense onto the sample overnight. Another Mg saturated sample was heated at 60C for two hours in ethylene glycol vapor which was then allowed to condense overnight. X–ray patterns for ethylene glycol treated slides of montmorillonite and beidellite standards were identical, showing expansion to about 17A. "Beidellite" was identified by its resistance to expansion when solvated with glycerol vapor (Harward and Brindley, 1964).

Potassium saturated slides were similarly prepared and subsequently heated to 110C and 550C. Vermiculite was indicated by collapse of 14A peaks to 10A after K saturation, drying at 110C, and x-raying at 0 percent humidity. Kaolin (Kaolinite or halloysite) was identified (in the absence of a 14A peak) by the disappearance of the 7A peak after heating a K-saturated sample for three hours at 550C. Chlorite was indicated by the presence of a 14A peak after 550C heating. Decreases in the size of the 7A peak with corresponding increases in the 14A peak due to 550C heating would have been an indication of chlorite, not kaolinite.

pH

The pH was determined by mixing the soil with water u it was the consistency of a paste. A Chemtrix Type 60A meter was used for the determination.

Ca/Fe Ratios

Calcium and iron were determined by using a Phillips x– spectrometer and a method of sample preparation modif from Borchardt and Theisen (1971). Briefly, air–dried soil sieved through a no. 40 sieve (420 um) and then added to a mm aluminum Spex cap containing polyvinyl alcohol as a ba ing material. This was pressed in a die assembly at 2300 kg/ (approximately 2300 tons per square foot) to form a smo surface.

Ca was determined by measuring the count rate of the C peak at 113.10°2θ. The chromium x–ray tube was opera at 30 kv and 10 ma. X–rays were detected with a LiF crystal flow–proportional counter operated in a less than 300 um v uum at 1530 volts. A pulse height analyzer was used with baseline at 4.0 volts, and the window at 11.0 volts.

Fe was determined by measuring the count rate of the F peak at 51.75°2θ. The chromium x–ray tube was operated at kv and 25 ma. X–rays were detected with a LiF crystal scintilation counter operated in air at 960 volts. A pulse hei analyzer was used with the baseline at 4.0 volts, and the wind at 20 volts.

The count rates for both Ca and Fe were compared direc to those for a standard andesite (USGS–AGV–1) which c tains 3.5 percent Ca and 4.73 percent Fe according to Flana (1973, p. 1190). This comparison was made after every th samples to correct for instrumental instability. Background matrix corrections were unnecessary because the backgrou count rates were insignificant and the matrix was similar for samples.

Color

Soil colors were determined by comparison to the stand Munsell soil color charts. When color names are given, the na refers to the first cited notation in parenthesis (Soil Survey St 1951, p. 203). For example, brown (10YR5/3d, 2/2 m) ref to the dry color, brown (10YR5/3d), and the moist color, v dark brown (10YR2/2m). This notation for dry (d) and m (m) colors is becoming more common in the literature (Bunt and others, 1977, p. 401) and avoids confusion in preparing f descriptions.

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